DOCTOR OF PHILOSOPHY

Three Essays on Environmental Economics and International Trade

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Award date:
2014

Three Essays on Environmental Economics and International Trade

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Submitted for the
Degree of Doctor of
Philosophy
Economic Studies
School of Business
University of Dundee

DEDICATION

To my family

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LIST OF ABBREVIATIONS

ADF:	Augmented Dickey-Fuller test
ARDL:	Autoregressive Distributed Lag model
BRA:	Brazil
CCR:	Canonical Cointegrating Regression
CGGDP:	Comparable Green GDP
CHN:	China
CKC:	Carbon Kuznets Curve (EKC estimation for CO_2)
CO_2:	Carbon dioxide
CTH:	Contracting Threshold Hypothesis
DF:	Dickey-Fuller test
DOLS:	Dynamic Ordinary Least Square
ECM:	Error Correction Model
EG:	Engle and Granger cointegration test
EKC:	Environmental Kuznets Curve
FEH:	Factor Endowment Hypothesis
FDI:	Foreign Direct Investment
FMOLS:	Fully Modified Ordinary Least Square
GDP:	Gross Domestic Product
GNP:	Gross National Product
GPI:	Genuine Progress Indicator
IMF:	International Monetary Fund
IND:	India
ISEW:	Index of Sustainable Economic Welfare
J-test:	Johansen test for cointegration (Johansen and Juselius, 1990)
KPSS:	Kwiatkowski–Phillips–Schmidt–Shin test for unit root
MG:	Mean Group estimator
OECD:	Organisation for Economic Co-operation and Development
OLS:	Ordinary Least Square
PHH:	Pollution Haven Hypothesis
PMG:	Pooled Mean Group estimator
PP:	Phillip-Perron test
PPP:	Purchasing Power Parity
PwC:	Price Waterhouse Coopers
PWT:	Penn World Table
SKC:	Sulphur Kuznets Curve (EKC estimation for SO_2)
SD:	Sustainable Development
SNDP:	Sustainable Net Domestic Product
SO_2:	Sulfur dioxide
TH:	Threshold Hypothesis
TY:	Toda and Yamamoto (1995) procedure
UK:	the United Kingdom of Great Britain and Northern Ireland
US:	the United States of America
USD:	United States Dollar
UN:	the United Nations
VAR:	Vector Autoregressive
VECM:	Vector Error Correction Model
WB:	World Bank
WTO:	World Trade Organisation
ZAF:	South Africa

ACKNOWLEDGEMENTS

I would like to express my sincere thanks and deepest gratitude to Professor Catia Montagna, Dr Yin Zhang, and Professor Hassan Molana for their guidance and supervision during the course of my PhD research at the University of Dundee. But for their unstinted guidance much of this work would have remained unaccomplished. I benefit greatly from Professor Catia Montagna, Dr Yin Zhang, and Professor Hassan Molana's intellectual input pertaining to both the methodological issues as well as empirical issues addressed in this thesis. Their critical reviews of the text at various stages have helped me immensely in structuring the study appropriately. Their affection and support at various stages of the work make it immensely difficult to acknowledge with words, but to that extent words reflect sentiment, I would like to express my deeply heart felt gratitude.

My gratitude is due also to all faculty members at Economic studies, University of Dundee for their helpful comments and continuous encouragements that helped me complete the study, in particular those of Professor Arnab Bhattacharjee, Professor Paul Allanson, Dr Dennis Petrie, Dr Bill Russell, and Dr Paul Seaman.

Sincere thanks to Mrs June Campbell and Mrs Adele Ferrier for their fantastic support on administrative matters and for their continuous encouragement.

I would like to express my gratitude to all my PhD colleagues at Dundee. Sincere thanks to Chai, Chang, Fumin, Homagni, Long, Matthew, Rosen, Sayantan, and Shaolin for their friendship support throughout the course of this study.

Finally, I owe the completion of this thesis to my family who stood by me selflessly and patiently all the way through. I am indebted to my wife Qianzhu Fan, to my parents Xinguang Wang, and Ruiqin Wang, to my parents-in-law, Yuansheng Fan, and Guilian Ma, for their understanding, encouragement and support that have made my education possible.

DECLARATION

I hereby declare that I am the author of this thesis. All references cited have been consulted, unless otherwise stated. All the work of which this thesis is a record has been done by myself. It has not been previously accepted for a higher degree.

Sean King Blaed

(Xuan Wang)

PhD Candidate

Date ……………

CERTIFICATION

I certify that Mr. Sean Blaed conducted his research under my supervision in the Department of Economic Studies, University of Dundee. Mr. Blaed, has fulfilled all the conditions of the relevant Ordinances and Regulations of the University of Dundee for obtaining the Degree of Doctor of Philosophy.

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Lecturer

Date..…………...

ABSTRACT

The environmental impact of international trade has become an important issue, especially in emerging economies, due to their increasingly important roles in world trade, economic and environmental issues. This thesis is concerned with understanding the relationship between trade and the environment in the context of four emerging economies: Brazil, South Africa, India, and China (BASIC) as well as Chinese provinces.

We first look at the relationship between economic growth, international trade and environmental degradation in BASIC. The attention is then turned to evaluate different and countervailing effects of international trade (scale, technique and composition effects) on the environment in Chinese provinces. In the last essay, we investigate empirically the impacts of international trade on China's sustainable development using Chinese provincial Green GDP data.

The main conclusions that can be reached from our studies can be summarised as follows. First, little evidence is found to support either the Pollution Haven Hypothesis or the Factor Endowment Hypothesis in BASIC countries, indicating that international trade is not leading to BASIC countries becoming pollution havens. This result should not come with surprise, since it is evident that international trade does not cause significant compositional changes towards dirty industries in BASIC. Second, we find evidence that trade openness and FDI inflows are "good for the environment" as they reduce pollution in Chinese provinces, thus indicating international trade does not lead to Chinese provinces becoming pollution havens. Last but not least, international trade has a positive non-linear effect on China's sustainable development, implying the relationship between international trade and sustainable development in Chinese provinces has an inverted-U shape.

Chapter 1: Introduction

The immediate motivation for this research is to investigate the impacts of economic growth and international trade on the environmental degradation in four developing countries: Brazil, China, India and South Africa; the effects of trade openness and FDI inflows on pollution in Chinese provinces; and the impacts of international trade on China's sustainable development. This introduction chapter consists of three parts. Section 1.1 provides the background and motivation of our study. Section 1.2 outlines our research aims and questions. Finally, section 1.3 lays out the structure of this thesis.

1.1 Background and Motivation

In the 21st century, one of the top threats to humanity is environmental degradation (United Nations, 2004). Environmental degradation refers to the reduction of the capacity of the natural environment to meet human needs. Environmental degradation may cause series of environmental issues such as climate change, global warming, ice melting, sea level rising, and water resources deterioration among others.

Since the early 20th century, the global air and sea surface temperature has gone up by about 0.8%, with about two thirds of the increase occurring since the 1980s, and continues to rise with a growing trend. Especially in the period 2000 to 2010, emissions of greenhouse gases have been growing by 2.2% per annum, compared with only 1.3% from 1970 to 2000, and this exacerbates global warming issue (IPCC 2014a). Global warming can lead to serious environmental disasters. Temperature rise due to global warming can accelerate melting of glaciers and ice cap. According to National Aeronautics and Space Administration (NASA), Arctic ice now is melting at an alarming rate of 9% per decade and Arctic ice thickness has decreased by 40% since the 1960s. Global glaciers melting leads to sea level rise, loss of coastal wetlands and barrier islands, greater risk of flooding in coastal and riverside communities, and even loss of species. If the current global warming cannot get eased, the US Geological Survey projects that two thirds of polar bears will disappear by 2050.

Not only do we observe global pollution such as climate change and global warming, but also local pollution such as sulfur dioxide (SO_2). SO_2 is a typical local pollutant that has significant impact on human health. Scientific evidence shows that short-term exposure to SO_2 emissions may cause an array of adverse respiratory effects, such as wheezing, chest tightness and shortness of breath; while long-term exposure to SO_2 emissions may be linked with respiratory illness, alterations in the lungs' defenses and aggravation of existing cardiovascular disease (Pope et al., 2007). Moreover, SO_2 is also the major precursor of acid rain, which has adverse impact on forests, freshwaters, soils, killing insect and aquatic life-forms as well as leading damage to buildings and human health (Likens and Bormann, 1974).

It is evident that these environmental issues are closely related to the increasing human economic activities. According to the latest IPCC report (2014a), "*it is 95% certain that humans are the "dominant cause" of global warming since the 1950s"*. One typical feature of the post-World War II economic boom (1950s-1960s) was rapid economic growth with excessive consumption of raw materials, energy and natural resources. Until the late 1960s, economy was growing almost at the same rate of natural resources depletion (Repetto et al., 1989, Pearce and Atkinson, 1993, and Hamilton and Clemens, 1999 among others). This conventional form of development, also known as the "Western Development Model" (Meadows et al., 1972), has raised worldwide concern over how long the finite world natural resources can fuel this rapid economic growth. Since the 1970s, the debate about the feasibility and desirability of future economic growth has thrived, and the popular imagination was captured by a study of the world economy known as "The Limits to Growth". In this 1972 Club of Rome report, Meadows et al. (1972) concluded that the conventional form of development had come to an end and the world was entering the "era of limits", because if present trends in population growth, industrialization, pollution, food production and resource depletion continued, the carrying capacity of the planet would be exceeded within the next 100 years. Then serious consequences would be ecosystem collapse, famine and war. Despite being criticised on both theoretical and empirical grounds, "The Limits to Growth" has at least underlined the importance of the environment for economic growth (Cole et al., 1973, Malenbaum, 1978, Nordhaus, 1992, Ekins, 1993, and Turner, 2008).

Furthermore, the increasing international integration and globalisation have also raised worldwide concern over their environmental impacts. Especially since the 1970s, advances in information, communications and transportation technology, such as the rise of more convenient telecommunication, internet and new transportation systems, have greatly increased human economic activities as well as the interchange of products, ideas and world views between countries, which generate further economic interdependence across the world promoting the process of international integration and globalisation. This increasing international integration has brought new challenges to humanity, especially with respect to the environmental issues – to the extent that it contributes to deforestation, global warming and climate change to name a few, which may have serious local as well as global impacts, such as melting glaciers, sea level rise and extreme weather events (Low, 1992, Posada, 1998, and Frankel and Rose, 2014).

However, due to the increasing economic interdependence, preventing and reducing the effect of environmental issues require international cooperative actions of all nations. This is the reason why most environment conferences convene multilateral meetings of governments. For example, one of the earliest global conferences on environmental issues was the United Nations Conference on Human Environment held at Stockholm in 1972, which was attended by representatives of 113 countries, 19 inter-government agencies and more than 400 inter-governmental and non-governmental organisations. Since then, modern political and public awareness of global environmental problems has been widely raised, promoting more conferences and urging more actions on environmental issues. Gradually, numerous and extensive international negotiations put forward environmental treaties demanding international efforts on protecting the natural environment. One of the famous environmental treaties is the Kyoto Protocol, which recognises that developed countries are principally responsible for the current high level of Greenhouse Gas (GHG) emissions in the atmosphere as a result of more than 150 years of industrial activity, and places a heavier burden on developed nations under the principle of "common but differentiated responsibilities" (United Nations, 1995). Thus in the Kyoto Protocol, developed countries are facing binding limitations on their greenhouse gas emissions, whereas developing countries are also committed to reduce their emissions but without any binding targets. Environmental treaties, together with the creation of free trade agreements and institutions, such as North Africa Free Trade Agreement (NAFTA) and World Trade Organisation (WTO), generate a worldwide concern that setting unbinding limitations for developing countries may lead to international competitiveness loss for developed countries, and that in turn international trade will lead to developing countries becoming pollution havens.

These worldwide concerns have resulted in a hot debate over the environmental impacts of economic growth and international trade in developing countries. On the one hand, developed countries argue that developing countries ought to impose more stringent environmental policies. Because developing countries generally impose lenient environmental policies, they enjoy a comparative advantage in dirty goods production, and thus international trade leads to developing countries becoming pollution havens as proposed by Pollution Haven Hypothesis (PHH). On the other hand, developing countries disagree and argue that international trade can help them grow and that whilst economic growth can first aggravate environmental degradation until a certain threshold, further economic development will first mitigate environmental degradation and then improve the natural environment, as asserted by the Environmental Kuznets Curve (EKC) hypothesis. Therefore, instead of tightening up environmental regulations, developing countries suggest that the way to solve the environmental issues resulting from their development is to give them an “equitable space for development”, i.e. allow them to “first pollute and then clean up” (Hallding et al., 2011).

However, although developed countries should take the main responsibility in global environmental issues such as in controlling Greenhouse Gas (GHG) emissions due to their historical emissions, developing countries are also significantly contributors, especially, the BASIC countries: Brazil, China, India and South Africa, which collectively account for about 60% of total annual greenhouse emissions from developing countries[1]. According to the World Bank[2], Brazil, China, India and South Africa are the 17th, 1st, 3rd and 13th CO_2 emitting countries in the world, accounting respectively for 1.32%, 23.50%, 5.83% and 1.46% of world total CO_2 emissions[3]. Although per capita CO_2 emissions remain low, particularly in Brazil and India, the growth rates of CO_2 emissions are high in these four countries. At the same time, BASIC countries are relatively large economies in their region and significantly contribute to world’s total exports and imports. Brazil, China, India and South Africa represent roughly 40% of the world’s population and 12% of global GDP, contributing respectively to about 38% of Latin America’s GDP, 35% of East Asia’s GDP, 80% of South Asia’s GDP and 31% of sub-Saharan Africa’s GDP (World Bank, 2014). In the case of international trade, BASIC countries together have an exports share of up to 12.64% of world merchandise exports and 7.6% of commercial exports, and a share of up to 11.53% of world total imports (International Trade Statistics, 2010). Thus it is important to examine if BASIC countries’ substantial economic growth and international trade have serious adverse effects on their natural environment for they may have huge impact on world’s environmental issues and sustainable development (as we shall detail in chapter 2).

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[1] World Energy Outlook, International Energy Agency (IEA), 2009.

[2] World Bank, ‘United Nations Statistics Division, Millennium Development Goals indicators 2009.

[3] We use CO_2 emissions rather than greenhouse gas emissions for our discussion about BASIC countries due to reasons as follows. Firstly, we cannot access detailed update greenhouse gas emissions data for these four countries. Secondly, since CO_2 emissions is an important indicator for greenhouse gas emissions – CO_2 emissions contribute upto 26% of greenhouse gas emissions (Kiehl et al., 1997), it is often assumed to be highly correlated with greenhouse gas emissions.

As the biggest developing country and the fastest growing emerging economy, China has performed unprecedented rapid economic growth during the past three decades, a performance that has arguably been greatly encouraged by the country's export-oriented policy and successful attraction of foreign capital inflows. According to World Bank's International Comparison Project (ICP), China has surpassed the US becoming world's largest economy in 2014 (IMF, 2014), and also world's largest exporter and second largest importer. China is too facing serious environmental issues. According to its Environmental Action Plan for 1991-2000 (China, 1994), the top seven priority environmental problems in China are: water pollution, especially contamination by organic waste; water shortage, particularly in northern China; urban air pollution including particulates and sulphur dioxide; hazardous and toxic solid waste in urban area; soil erosion; loss of forests and grasslands. These environmental issues have been causing great damages to Chinese people's life. For instance, about 85% of the length of China's six biggest rivers are polluted, so is about 60% of its underground water; a massive number of cities are facing shortage of drinkable water (Xinhua News Agency, 2002); many Chinese cities have to experience frequent heavy smog days every year; one in three Chinese people living in urban area are breathing polluted air; and acid rain covers one third of the whole country (The Economist, 2014a). These environmental damages have resulted in huge costs to Chinese economy as well as to its people's health. It is estimated that the economic cost of pollution can be up to 10% of China's total GDP, and up to 760,000 premature deaths every year in China are suspected to be related to air and water pollution (World Bank report 2007). It is argued that environmental issues are becoming the bottleneck for China's future economic growth. In the 2013 annual sessions of the National People's Congress, Prime Minister Li Keqiang said that China's environmental issues made him quite upset and the time had come for China to "declare war" on pollution.

Regional disparities are important for the relationship between environmental degradation and international trade in Chinese provinces. China faces obvious regional disparities, partly as a result of government policies that have been giving preferential support to the coastal areas since the beginning of China's economic reform in the late 1970s. Despite the government's subsequent attempts to rebalance support towards other regions, coastal provinces are relatively richer and with higher level of international trade (as we shall detail in chapter 3). However, there is no clear evidence that richer provinces have significantly higher level of pollution than the poorer provinces. This raises the concern that instead of the whole of China becoming, as a developing country, the pollution haven, only relatively poorer provinces may find them becoming the pollution havens for developed countries. Therefore, in order to answer this question, it is meaningful to investigate the environmental impacts of international trade at Chinese provincial level.

Furthermore, GDP increase from economic growth may not be necessarily of benefit to a nation's true welfare. As is increasingly argued, GDP may not be a good indicator for human well-being, for it misses many important factors that influence human well-being, among which the environment is prominent. Measuring real well-being is important, because even if GDP rises, the real well-being may still go down if the costs from adverse environmental effects outweigh the benefits from GDP growth. These considerations underpin the attention being increasingly directed in both academia and policy circles to the development of a "better" well-being indicator. The existing literature offers hundreds of attempts in calculating environmentally adjusted GDP, or Green GDP, for numbers of countries (as we shall detail in chapter 4). The Chinese government has also tried to establish a Green GDP accounting since 2004. However, due to data availability, China's Green GDP project was officially suspended indefinitely in March 2009 (China Economic Review, 2009). Arguably compared to other countries, China needs a Green GDP more, for it is widely believed that the country is facing serious environmental issues and has unneglectable pollution costs. Therefore, it is important to evaluate if China's rapid growth in income and trade are actually benefiting to Chinese people's real well-being. Moreover, giving the significant regional disparities, Green GDP for provincial level is preferred to the national total Green GDP, for it can provide a better understanding of the regional well-being disparities in China.

1.2 Key Hypotheses and Concepts

Promoted by "The Limits to Growth" and debates on the environmental impacts of economic growth and international trade, various hypotheses and concepts have been put forward, among which three have had the greatest impact: the Environmental Kuznets Curve (EKC) hypothesis, the Pollution Haven Hypothesis (PHH) and the concept of Sustainable Development (SD). In this section, we shall briefly introduce the basic concepts of EKC hypothesis, PHH, and SD.

In a broad sense, the Environmental Kuznets Curve (EKC) hypothesis, the Pollution Haven Hypothesis (PHH) and Green GDP can all be related to sustainable development. For instance, if the income-pollution relationship in developing countries follows an inverted U shape EKC, then the "first pollute and then clean up" policy can be a choice for developing countries, because even if the economic development in developing countries is polluting to start with, it will lead to future environmental improvements – and hence these countries can pursue sustained long run growth. In other word, economic development can follow a sustainable development path. The PHH suggests however that, economic growth in developing countries may not be on a sustainable development path, if developing countries are pollution havens for developed countries. The PHH implies that the environment in developing countries are overused to meet demand for other countries: to the extent that developing countries are pollution havens for developed countries, their environment is overused, its ability to meet future needs is decreasing, and economic development is not sustainable. It is also argued that sustainable development calls for better indicators than GDP for measuring well-being, Green GDP measures have been proposed that adjust the conventional GDP with environmental costs as one step further towards a better measure of sustainable development.

1.2.1 EKC hypothesis

In the early 1990s, a group of empirical studies (Grossman and Krueger 1991, 1993, and 1995, Shafik and Bandyopadhyaya, 1992, Panayotou, 1993, Selden and Song, 1994) found evidence of an inverted U shape relationship between economic development and environmental degradation. This inverted U shape relationship is first coined by Panayotou (1993) as the 'Environmental Kuznets Curve (EKC)' due to the resemblance of the inverted U shape relationship between economic growth and income inequality, known as the 'Kuznets Curve' named after the Nobel laureate Simon Kuznets. The Environmental Kuznets Curve (EKC) hypothesis asserts, in the early stages of economic development, per-capita income increases raise environmental degradation until a threshold (or turning point) is reached, after which further income increases reduce environmental degradation (figure 1.1).

Empirical studies of EKC have sparked debates on the causes of this inverted U shape relationship. Various theoretical studies have been put forward by economists to explain the inverted U shape relationship. Theoretical explanations of EKC are generally along with two big streams: production side studies and consumer side studies. The production side studies seek to find the cause of the EKC from supply side factors, such as structures of production, efficiencies, use of new or different fuels and materials, and external influences such as government policies. Whereas, the consumer side studies focus on the factors from the demand side, such as structures of consumption, preference, price of environmental quality, and information and its acquisition (Pearson, 1994). These theoretical explanations can also be broadly categorised into five main groups: structural changes, technological and organisation changes, behavioural and preferences changes, institutional changes, international reallocation. De Bruyn and Heintz (2002), Dinda (2004) and Kijima et al. (2010) provide detail reviews. In this section, we briefly review these explanations as follows.

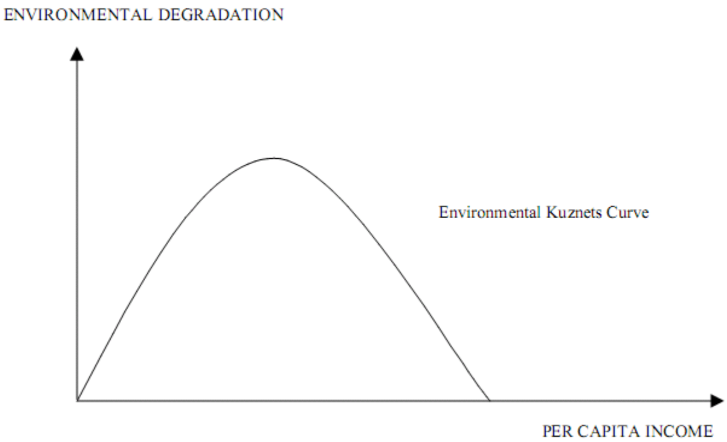

Figure 1.1: EKC inverted U shape

Structural changes

Early attempts of explaining the EKC are made by Grossman and Krueger (1991) and Panayotou (1993), who propose a logical explanation for the inverted U shape from the view of structural changes in the economy. A common economic growth path revealed by many developed countries is from agricultural to manufacturing and then to the service industries. Insomuch as it is widely believed that agricultural and service industries are relatively cleaner than the manufacturing industries[4], as economy develops from agriculture to manufacture and then to service, the accompanied environmental degradation should first go up and then fall down. Therefore structural changes in economy, such as from labour intensive to capital intensive and then to knowledge-based technology intensive industry, may present an inverted U shape relationship between environmental degradation and economic development. This explanation is based upon the development process in the production side.

Technological and organisation changes

Another explanation of EKC also from the production side is put forward by Komen et al. (1997). Instead of transforming between dirty and clean industries, Komen et al (1997) argue that wealthy nations are also more affordable for technology development. For instance developed countries generally have high Research and

[4] This argument is based on the assumption that manufacturing industries generally consume more energy and produce more pollution (Antweiler et al., 2001, Dasgupta et al., 2002 and Copeland and Taylor, 2004).

Development (R&D) expenditure, so they can afford to replace the dirty and obsolete technologies with upgrade and cleaner technologies, and in turn reducing pollution as economy grows. Komen et al.'s (1997) argument is based on the assumption that technology innovations will always be beneficial to the environment. Although this assumption is debatable, because some technology innovations may lead to more energy consumption possibly resulting in more pollution, on average innovations in technology and organisation are likely to improve production efficiency and therefore be beneficial to the environment.

Moreover, as environmental protection pressure increases, companies may reconsider their production process (Steger, 1996) and gradually shift to more environmental-friendly 'green thinking', which may help to build up their reputation of environmental-friendly among customers and promote their names. Thus companies may be self-motivated and want to adopt greener technologies as well as improve their organisational efficiencies, such as waste products recycling, which reduce their pollution intensity.

Furthermore, technology and organisation changes may also alleviate environmental degradation though changing the input mix of materials and fuels. Technology upgrade and 'green thinking' of organisation may require replacing the old dirty input to new clean input, which generates less pollution causing less detrimental environmental impact. This material substation is an important element of advanced economies (Labys and Wadell, 1989).

Lastly, a self-regulatory market mechanism may create a bell shape pollution-income pattern by itself (World Bank, 1992, Unruh and Moomaw, 1998), because in the early stages of economic development, economic growth is often associated with large consumption and heavy exploitation of the natural resources, but as natural resources further deplete, the prices of natural resources will go up. The increase in natural resources prices may alleviate the exploitation of natural resources, and therefore accelerate the shift toward less resource-intensive technologies (Torras and Boyce, 1998), and in turn reducing pollution. One good example of this explanation is the oil crises in the 1970s, which promoted a shift from conventional polluted energy (coal, oil and gas) to alternative cleaner energy, such as hydropower and nuclear power.

From the intuition of technological and organisational changes, Tahvonen and Salo (2001) consider a theoretical model where firms accumulate technical knowledge and choose between non-renewable and renewable energy resources. Tahvonen and Salo (2001) find that there may be an inverted U shape relation between carbon emissions and income level even without environmental policies, because in the early stages of development, non-renewable energy resource is cheaper relative to the price of renewable energy resource, firms choose to use non-renewable energy resource and therefore pollution rises; however as economy grows, firms accumulate technical knowledge for the use of renewable energy resource, while non-renewable resource becomes more difficult to extract, thus the price of renewable energy resource becomes relatively cheaper to non-renewable resource, firms shift to renewable energy resource and pollution reduces. Tahvonen and Salo's (2001) theoretical model reveals that the technology change is the main driving factor for the EKC.

Brock and Taylor (2004) also emphasise on the technological effect, so they modify the Solow model by incorporating technological progress in abatement, dubbed as the "Green Solow" model. They find when economy converges to a sustainable growth path, the EKC emerges for both the flow of pollution and the stock of environmental quality.

<u>Behavioural and preferences changes</u>

In contrary to the production side explanations, an alternative logic from the consumption side is related to the consumers' willingness to pay for the clean environment (Pezzy, 1992, Selden and Song, 1994, and Baldwin, 1995). In the early stages of economic development, because the natural environment is not heavily polluted while standard of living is low, consumers are more interested in income, giving high priority to increasing material output and willing to bear the natural environment deterioration; whereas, in the later stage of economic development, income level is high but the natural environment deterioration is worse, so consumers are willing to pay more for clean environment than income. This explanation of the EKC argues that people attach increasing value to environmental amenities. In this case, the environmental is treated as a luxury good with the income elasticity of demand of environment is higher than one, so after a certain income level, the willingness to pay for a clean environment rises by greater proportion than income. Thus after reaching a high level of standard living, consumers may donate more to environmental organisations, select more environmental friendly products, and give stronger support to environmental friendly policies.

In the line of theoretical studies for behavioural changes and preferences, Lopez (1994) is one of the early attempts that consider environmental resources as factors of production. By completely internalising environmental externalities, Lopez shows if producers are forced to pay a price for their emissions, then the relationship between pollution and income depends on properties of the price paid for pollution, technology and preferences. When polluters pay a constant price for their emissions, an increase in income is accompanied by a rise in pollution. Even if polluters pay for the true social marginal costs of pollution, as long as the welfare function is of homothetic preference, pollution is ever increasing with economic growth. However, when consumers have non-homothetic preferences, economic growth increases the value of the environment for consumers, and thus the inverted-U shape emerges. The intuition behind Lopez (1994) model is as follows: on one side, if firms have to pay an increasing price for pollution to meet the marginal costs, when the price reaches certain level, it is less costly for firms shifting from old and polluting technology to new and cleaner technology, and therefore causing less pollution. On the other side, consumers of non-homothetic preference are willing to given up additional consumption for cleaner environment, which depresses the pollution level. Lopez's model reveals that the inverted-U shape EKC may be a joint result from technological and organisational changes as well as behavioural and preferences changes.

John and Pecchenino (1994) consider an overlapping-generations model in which short-lived individuals make decisions that have long-lasting effect on both factor productivity and the environment. In John and Pecchenino's (1994) model the inverted U shape relationship between income and the pollution emerges, due that the early generation has too little income to spend on environment and then pollution rises as income increases, but after a certain period, when the income level is higher, the later generation can afford to pay for better environment and then pollution begins to fall.

Selden and Song (1995) use the neoclassical environmental growth model of Forster (1973) to study the relationship between economic growth, pollution and abatement effort. Selden and Song (1995) posit a J shape curve for abatement and assume the optimal abatement is zero at early stages of development until a critical level of development, but increases at an increasing rate thereafter. The pollution level in Selden and Song (1995) model first rises due that social planner spends no money for the environment quality at beginning, and then reduces after certain level of degradation when the social planner begins to allocate resources for better environment.

McConnell (1997) develops a simple static model exploring the role of income elasticity of demand for environmental quality. Instead of treating pollution as a by-product from production side as in aforementioned models, McConnell assumes pollution coming from consumption but reduced by abatement, so the social planner maximises utility subject to the income constraint (the sum of consumption and abatement). McConnell finds there is no particular role of income elasticity equal to one, pollution can decline even with zero or negative income elasticity when pollution causes a reduction the output, and the inverted-U shape EKC emerges due to higher income elasticity results in slower increases or faster declines in pollution.

Institutional changes

Panayotou (1993) attributes the bell shape EKC to policy distortions and market failures, such as subsidisation of energy consumption, ill-defined property rights for natural resources, and lack of payment for environmental externalities. In the early stages of growth, policy distortions and market failures reduce the operation costs of polluting companies. Thus policy distortions and market failures may stimulate economic growth, but at the same time also encourage the consumption of natural resources, aggravate environmental degradation, produce pollution, and result the upward sloping part of the bell shape EKC. In the late stage, removal of policy distortions and market failures, such as removal of subsidisation of energy consumption, establish property rights for natural resources and internalise environmental externalities, will discourage excessive consumption of natural resource and therefore alleviate environmental degradation causing the downward sloping part of the bell shape EKC.

Furthermore, in the early stages of economic development, the public may not be aware of the serious consequences of the environmental degradation, so may not give much pressure to government's environmental policy, as a result pollution is not controlled. However, as the standard of living improves, after the public realise the serious consequence of environmental degradation, then they will increase their support for environmental policies via elections and referenda forcing government to adopt stringent environmental policies, which may improve the environment. As argued by Grossman (1995), "*the demand for a better environment and the resulting policy response are the main underpinnings behind the decreasing path of the Environmental Kuznets Curve*".

To investigate the effect of institutional changes on the relationship between pollution and income, Lopez and Mitra (2000) study the bargaining problem between the incumbent government and private sector. They find irrespective of the type of interaction between the government and firm, the corruption may not preclude the existence of an EKC, for any income level the pollution levels are always above the social optimal level, and the EKC turning point takes place at income and pollution levels above those corresponding to the social optimum.

Andreoni and Levinson (2001) introduce a one-person model with a utility function of consumption and pollution. They show that the relationship between pollution and income depends on the returns to scale of abatement, and the inverted U shape EKC emerges when the abatement exhibits increasing returns to scale. Egli and Steger (2007) extend Andreoni and Levinson (2001) model and develop a simply dynamic EKC model addressing the optimal investment policy in terms of taxes. They find that the shape of the EKC is strongly affected by the degree of increasing return to scale and the environmental policies.

International relocation

The international reallocation of dirty industries from developed countries may cause a pollution reduction in developed countries while lead to a rise in pollution in developing countries (Hettige, Lucas and Wheeler, 1992, Arrow et al., 1995, Stern et al., 1996, Ekins, 1997 and Rothman, 1998). If the international reallocation of dirty industries is the main contribution to the inverted U shaped EKC in developed countries, then the inverted U shaped EKC found in developed countries are at the cost of increasing pollution in developing countries, so the overall pollution in the world may be not changed. Moreover, the development path of developed countries cannot be mimicked by developing countries, because eventually there will be no place for developing countries to shift their dirty production. If that is the case, developing countries have to figure out their own way of fighting against pollution.

Alongside these theoretical studies, enormous empirical studies have published too (detail review is provided in chapter 2). However, as pointed out by Dasgupta et al. (2002) and de Bruyn and Heintz (2002), empirical EKC studies fail to provide evidence that EKC exists in all countries for all pollutions, therefore our chapter 2 fills in this gap by empirically investing the EKC hypothesis of two pollutions (one global pollution, CO_2 emissions and one local pollution, SO_2 emissions) in BASIC countires. Therefore the first question this thesis addresses is:

(1) How important is the impact of economic growth and international trade on BASIC countries' environment?

Having performed impressive growth with high degrees of international openness, concern is often expressed that BASIC countries' economic success is at the cost of their environment. Due to BASIC countries' significant shares in world's GDP, trade and pollution, the relationship between economic growth, international trade and environmental degradation in BASIC countries has a notable influence on world environmental issues and sustainable development. Thus, a causality study on the relationship between economic growth, international trade and pollution in BASIC countries can help the design of environmental policies in BASIC countries.

An empirical EKC hypothesis study for BASIC countries is particularly meaningful. If economic development in BASIC countries is following an inverted U shape EKC path, then the "first pollute and then clean up" strategy can be an option for BASIC countries. However, a linear relationship between economic development and environmental degradation would lend support to the argument proposed by developed countries that BASIC countries should impose stricter environmental regulations and adopt to more environmentally friendly economic development models.

An empirical assessment of the PHH for BASIC countries can also help them to design their trade policies, since international trade policy and environmental policy are often connected due to the close relationship between international trade and environment. An early real world example is the US-Mexico tuna-dolphin conflict in 1991, when the US government prohibited the import of tuna from Mexico because of their detrimental fishing method. The US declared that tuna import from Mexico harmed the environment; Mexico argued that the US's ban was a violation of the rules in the General Agreement on Tariff and Trade (GATT) (the predecessor of the World Trade Organisation,WTO), because the US forced its domestic legislation on activities taking place out of its own territory. Similar trade-environment conflicts, including the shrimp-turtle conflict and the hormone-treated beef conflict, reveals different attitudes on the trade-environment relationship between developed countries and developing countries (Brack, 2013). On the one hand, developed countries argue that developing countries are gaining comparative advantage in producing dirty goods due to their less stringent environmental policies. Thus developed countries often blame developing countries for polluting the world by exporting goods produced with less environmentally friendly methods. On the other hand, developing countries argue that their relatively lax environmental regulations are due to their relatively low level of development and that only after having reached certain levels of economic development will they be in a position to improve environmental regulations.

1.2.2 PHH

Standard international trade theory argues that even if one country is more efficient in producing all goods (absolute advantage) than the other, both countries will still gain by trading with each other as long as they have different relative efficiency. In other words, trade is governed by comparative advantage. If environmental policy is a source of comparative advantage, tightening up environmental policy reduces net exports and/or net incoming FDI in the affected industries, ceteris paribus. This is called as the Pollution Haven Effect (PHE). Following the logic of the Pollution Haven Effect (PHE), for given levels of environmental policy, liberalising trade or foreign investment causes polluting industries (firms, plants or production facilities) to relocate to countries with weaker pollution regulations. This is known as the Pollution Have Hypothesis (PHH). It is important to distinguish between the Pollution Haven Effect (PHE) and Pollution Haven Hypothesis (PHH), since it may have large impacts on policy issues (Copeland and Taylor, 2004). The Pollution Haven Effect (PHE) argues pollution regulations have effects on plant location decisions and trade flows of dirty industries, because stringent pollution regulations are a comparative disadvantage. By contrast, the Pollution Have Hypothesis (PHH) postulates a reduction of trade barriers leading to the shift of pollution-intensive industries from countries with stringent pollution regulations to countries with lax pollution regulations. So, it is possible that the PHE exists, but the PHH fails, if some other factors dominate the PHE and overturn the relocation decisions of dirty industries (Copeland and Taylor, 2003, and Levinson and Taylor, 2008).

The impact of trade liberalisation on the environment has distinctive and sometimes countervailing effects (as we shall detail in chapter 3). Broadly speaking, international trade affects the environment through two effects: a direct effect and an indirect effect. The direct effect refers to activities induced by international trade, such as transport activities, which lead to increase in energy consumption generating pollution (Cristea et al., 2013). Moreover, international trade may also affect the environment indirectly through trade induced scale effects, technique effects and composition effects (Grossman and Krueger, 1991, Antweiler et al., 2001, Copeland and Taylor, 2003 and 2004 among others). Trade induced scale effects refer to the changes in the total size of the economy caused by international trade. Holding all other things constant, if international trade raises the size of the economy, then trade induced scale effects raise pollution. Trade induced technique effects refer to the effect of technology improvement caused by international trade. International trade may introduce more efficient technology though import penetration [5], export driven competition[6], and technology spillover (Blomström et al., 1999, Sjöholm, 1999, Crespo et al., 2002, Blalock et al., 2005, Madsen, 2007, and Bloom et al., 2008 among others).

[5] More efficient technology is embedded in the import goods.
[6] Export competition stimulates firms with low level technology to update their technology for international competition.

An improvement in technology induced by international trade reduces energy consumption and pollution, ceteris paribus.

Contrary to trade induced scale and technique effects, trade induced composition effects are relatively more complicated for they are subject to countries' comparative advantage. Traditional international trade theory tells us that trade is governed by comparative advantage, which postulates that the efficient exchange of goods leads to optimal outcomes in terms of resource allocation and welfare. According to the existing literature on the link between international trade and the environment (that we shall detail in chapter 3), factor endowments and technology are not the only sources of comparative advantage: the stringency of environmental regulations is also important and can be a source of comparative advantage. Consistent with the Pollution Haven Hypothesis (PHH), since developing countries tend to have relatively lenient environmental regulations, they will exhibit comparative advantage in producing and exporting relatively 'dirty' goods, whilst developed countries, with more stringent environmental regulations, will specialise in the production and exports of 'cleaner' commodities. Thus, the stringency of environmental regulations can contribute to developing countries becoming 'pollution heaven' as a result of international trade and investment[7]. In contrast, if factor endowment were the main and only source of comparative advantage (Factor Endowment Hypothesis), international trade will lead to developed countries becoming pollution havens, because developed countries are relatively capital abundant, and thus have a comparative advantage in producing 'dirty' goods[8], developed countries will specialise in dirty goods production, exports dirty goods, and imports clean goods.

It can be seen that the Pollution Haven Hypothesis (PHH) and Factor Endowment Hypothesis (FEH) can predict opposite trade induced composition effects for developing countries. PHH and FEH can be illustrated by means of a theoretical framework. For illustration proposes, we adopt the model developed by Copeland and Taylor (2004) for both PHH and FEH. The model focuses on production-generated pollution in two countries (North and South) producing two goods (X and Y) which differ in pollution intensity, where X is the 'dirty' good with price p expressed in terms of good Y which is the clean good used as the numeraire; production of both goods

[7] An important dimension of the pollution haven hypothesis concerns the role of Foreign Direct Investment – whereby (partly as a response of different environmental regulations) industrial economies transfers (offshore or outsource) the polluting phases of production to LDCs.

[8] Here we follows the existing theoretical studies (detail review in chapter 3) and assume that capital intensity means dirty, however, in chapter 3, we have shown that this assumption may not be proper.

requires two input factors: capital (K) and labour (L), denotes the pollution emission intensity which is affected by environmental taxes and the equilibrium output of X. Let an asterisk denote Southern variables. To illustrate the pollution haven and factor endowment mechanism, Copeland and Taylor (2004) adopt the comparative advantage approach common in the traditional international trade literature, which employs a relative demand and supply analysis for the two goods (as shown in figure 1.2 and 1.3).

North and South are assumed to be identical except for their pollution policies and relative factor endowments. Because preferences are assumed to be identical and homothetic, and demand decreases as price rises, there is only one common downward-sloping demand curve (denoted as RD) in figure 1.2 and 1.3. Instead, the relative supply curve (denoted as RS) is upward-sloping.

To isolate the pure Pollution Haven Hypothesis (PHH), factor endowments are assumed to be identical and exogenous across countries, but pollution policies differ. The South is assumed to have relatively weaker pollution policies, in the form of a lower pollution tax; as a result, the X industry is relatively bigger, whilst the Y industry is relatively smaller, in the South and in the North. Thus, the country with a relatively weaker pollution policy produce more X for a given p since, due to the different tax rates, the autarky relative price is higher in the North than in the South, . Thus, the South has a comparative advantage in the ‘dirty’ good X, while the North has a comparative advantage in the ‘clean’ good Y. Thus the relative supply curve for the South (RS*) lies to the right of that for the North (RS).

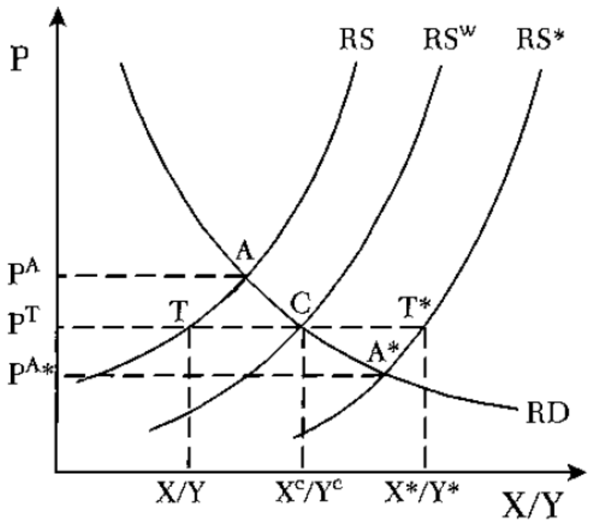

Figure 1.2: PHH (sourced from Copeland and Taylor, 2004)

As a result of this comparative advantage pattern, if trade opens up, the South will specialise in the production of good X and the North will specialise in producing Y. North's equilibrium would move from A to T and that of South would move from A* to T. This contracts dirty good production in the North and stimulates it in the South. The world supply curve is a weighted average of the RS* and RS, and lies in between of the two autarky relative supply curves. Thus, trade induced by pollution policy differences creates a pollution haven in the country with weaker policy.

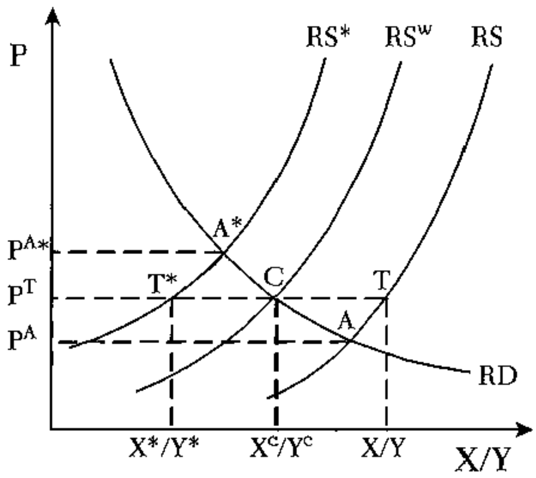

Figure 1.3: FEH (sourced from Copeland and Taylor, 2004)

In contrast, to isolate the pure Factor Endowment Hypothesis (FEH), pollution policies are assumed to be identical and exogenous across countries, but factor endowments differ. The North is now assumed to be relatively capital abundant so that , hence the autarky relative price of X is lower in the North than in the South, and therefore North has a comparative advantage in producing dirty good. Contrary to the PHH case, once trade is opened up, the North will specialise in the production and export of the 'dirty' good and will import good Y. In this case, trade will result in an increase in pollution in the North which becomes the pollution haven.

There is a growing literature on the theoretical studies of the Pollution Haven Effect (PHE) and Pollution Haven Hypothesis (PHH). These theoretical studies may be broadly divided into three groups. Most early theoretical studies focus exclusively on environmental policy and assume environmental policy by itself can change trade patterns and cause pollution haven. However some argue that the reason why some empirical studies fail to find any evidence for the PHH is, because trade is not only influenced by the stringency of environmental regulations, but also by some other factors such as factor endowment. Thus, the second group of theoretical studies try to investigate the PHH with consideration of environmental policy as well as other factors. Lastly, there is one interesting group of theoretical studies arguing that the PHH may not be necessarily related to environmental regulation. Instead, the PHH may still hold in the absence of any environmental regulation.

The first group of theoretical studies is theoretical attempts focusing on the effect of environmental policy on trade patterns. Pethig (1976) introduces a simple two-sector general equilibrium model, where pollution is generated as a by-product of the production process and treated as a factor of production. Pethig (1976) shows that a country with relatively less stringent environmental policy exports and specialises in the production of environment-intensive goods. This echoes the postulation of the Pollution Have Hypothesis that international trade leads to countries with lax environmental regulation becoming pollution havens. McGuire (1982) incorporates an environmental factor into the Heckscher-Ohlin model and finds that when factors are allowed to be mobile, the environment regulating country is driven out of producing the regulated good. That is to say, if developed countries impose environmental regulations while developing countries do not, production of dirty good will migrate to developing countries. Theoretical studies, which may fall into this group also include Siebert et al. (1980) and Levinson and Taylor (2008) among others.

One limitation of the early theoretical studies is that environmental policy is assumed to be exogenous. As a result, their analysis of trade patterns merely reflects exogenous pollution policy changes. Copeland and Taylor (1994) endogenise pollution policy in a simple static North-South trade model by inking the stringency of environmental regulations with national income levels. They show that if pollution tax is determined endogenously, government simply sets pollution tax equal to the marginal damage caused by pollution emissions, and pollution tax is increasing in income since environmental quality is a normal good. Because rich countries have relatively higher income, rich countries choose higher pollution tax, and consequently, force all pollution-intensive industries to relocate to poor countries. Copeland and Taylor (1994) consider environmental quality as a local public good, which means pollution is treated as a local public bad that is confined to causing damage only in the emitting country. Obviously, this is not the case for global pollution, such as Greenhouse Gas emissions, which have much greater global impact rather than local impact. Copeland and Taylor (1995) propose a two-region (North and South) model treating environmental quality as a global public good, assuming pollution affects all countries. Copeland and Taylor (1995) find that if countries have sufficiently similar effective labour endowments, factor prices are equalised by trade, then trade raises the pollution generated by the South and lowers the pollution generated by the North, but leaves the world pollution level unaffected. However, if countries have substantially different human-capital levels, factor prices are not equalised by trade, then the North specialises in human-capital-intensive goods and the South specialises in pollution-intensive goods. In this case, free trade reduces pollution in the North and raises pollution in the South, but results in a higher global pollution level than in autarky. Elbers and Withagens (2004), Regibeau and Gallegos (2004), and Broner et al. (2012) also contributed to this strand of literature.

The second group of theoretical studies argue that the environmental impact of international trade may not only depend on income-induced changes in environmental policy, but also may be influenced by other factors, such as relative factor abundance. Copeland and Taylor (1997) consider a two-good model with two production factors: capital and labour, in which the North is assumed to be rich as well as capital abundant. The Heckscher–Ohlin theorem predicts that a capital abundant country exports the capital-intensive good, while the labour abundant country exports the labour-intensive good. Since the North is capital abundant, the North exports and specialises in dirty goods. But at the same time, the North has relatively higher income level, so the North has more stringent environmental policy, which should also force dirty production process out of the country. Thus, Copeland and Taylor (1997) argue that the environmental impact of trade is determined by the interaction between capital abundance and income-induced pollution policy. If the difference in factor abundance dominates the difference in income levels, pollution intensive industries shift to the capital abundant country, the North, where pollution regulation is also stricter, then trade causes a decline in world pollution, vice versa. This theoretical study is interesting because it demonstrates that the environmental impact of international trade is the result of two competing hypotheses: the Pollution Haven Hypothesis (PHH) and the Factor Endowment Hypothesis (FEH).

Both the PHH and FEH focus on the trade induced composition effect. However, as proposed by Grossman and Krueger (1991, and 1993), the environmental impact of trade may be decomposed into three effects: scale, technique and composition effect. To isolate and identify the aforementioned three trade induced effects, Antweiler et al. (2001) (ACT hereafter) develop a general equilibrium model, in which pollution emissions are assumed to be generated from dirty production and determined by the total output level (scale effect), share of dirty output (composition effect) and pollution intensity of the dirty industry (technique effect). As the three effects do not necessarily work in the same direction, the ACT model predicts that the full environmental impact of international trade in a small open economy depends on the country's trade pattern and elasticity of marginal damage with respect to income. For a country exporting clean goods, the full effect of international trade is to lower pollution emissions. For a country exporting dirty goods, if the elasticity of marginal damage with respect to income is below one, then international trade will raise pollution; if the elasticity of marginal damage with respect to income is above one, then international trade will lower pollution (Antweiler et al., 2001).

Last but not least, even without any environmental regulation, some other factors such as differences in properties rights may also affect trade pattern creating pollution haven. Chichilnisky (1994) considers a North-South model of two identical countries which differ solely in their property rights on environmental resources: the North has well-defined property rights whereas the South has ill-defined property rights. Because well-defined property rights fully internalise environmental externalities, whereas ill-defined property rights are likely to cause overuse of environmental resources, the supply curve for environmental resources in the country with ill-defined property rights lies below that of the country with well-defined property rights. Thus, for a given price level, the country with ill-defined property rights, the South, is willing to supply more environmental resources, giving the South a comparative advantage in the production of resource-intensive goods. Therefore, international trade leads to the South overusing its environmental resources, exporting and specialising in resource-intensive goods. Chichilnisky (1994) concludes that since developing countries generally have ill-defined property rights on environmental resources, international trade leads to developing countries becoming pollution havens.

Schematically the logical skeleton of the PHH may be disentangled into five channels as in figure 1.4. As proposed by Taylor (2005), country characteristics such as access to various production technologies, opportunities for abatement and country specific endowments of productive factors, together with the world prices determine national income level, which in turn maps into environmental regulations (or other regulations such as property rights) as represented by arrow 'a'. In channel 'b', environmental regulations have effects on the production costs of different industries, which changes the relative price structure in the country. For instance, imposing a pollution tax raises production costs in polluting industries (i.e. the PHE), but may have little or insignificant effect on clean industries. However, if tightening up environmental regulations fosters innovations and adoptions of clean technologies leading to efficiency improvement in the production process as proposed by the Porter Hypothesis (Porter, 1991 and Porter et al., 1995), then the net effect of environmental regulations on firms' productivity may be ambiguous. But as long as relative production costs change, a nation's comparative advantage may change, altering trade and FDI flows in channel 'c'. If other factors such as factor endowments and property rights are also considered, the effect of a nation's comparative advantage depends on the interaction between environmental regulations as well as other factors. Therefore it may not be so clear-cut that stringency of environmental regulations significantly influences a nation's comparative advantage, and thus the impact of environmental regulations on trade patterns may be ambiguous. If the changes in production costs do not alter much of the relative price of a nation's comparative advantage, then trade and FDI flows will not be affected much either. But if trade and FDI patterns do change as environmental regulations tighten up and production costs rise, changes in the trade and FDI flows also affect a nation's pollution, income and perhaps the relative world price (channel 'd'). At the last stage, changes in a nation's pollution, income and prices affect country characteristics (channel "e") and in turn may alter the mapping from country characteristics to environmental regulations. This schematic analysis reveals that in a general equilibrium system, the relationship between trade and the environment may be simultaneously determined.

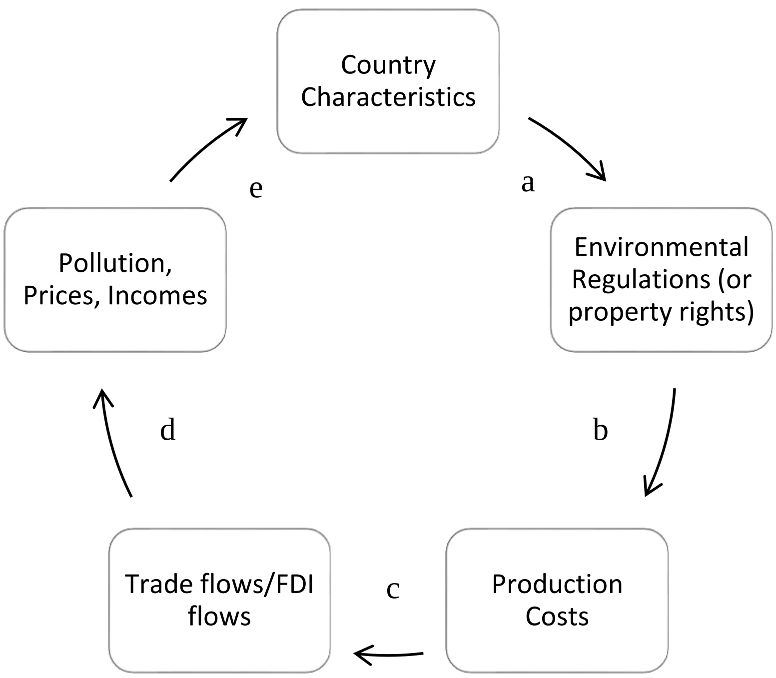

Figure 1.4: A schematic representation of the Pollution Haven Hypothesis (PHH)

Most existing PHH and FEH studies focus on national level investing sstrade between developed and developing countries. However in real world, there exists significant heterogeneity in economic development inside a developing country such as China, as we shall detail in chapter 3. Regional economic development heterogeneity in developing countries rises an interesting question that poor regions in a developing country instead of the whole developing country become pollution havens for developed countries. Utilising provincial level data of China, chapter 3 provide an empirical study addressing this question. Therefore the second question this thesis addresses is:

(2) What is the environmental impact of China’s notable economic growth and international trade? In particular, are some specific Chinese provinces becoming pollution havens?

Since 1978, China has experienced notable economic reform; the Chinese economy has been reformed from a cent c planned economy to a market-oriented economy. This economic reform has brought China double digit growth for more than 30 years, large amount of exports, imports and foreign investments every year, as well as serious environmental degradation. Although contributing remarkable shares of world GDP and international trade, China’s economic and trade activities are often criticised as not being consistent with sustainable development due to their detrimental effects on China’s natural environment. This is not in line with evidence that points to China’s economic growth being actually relying on decreasing levels of energy, and in turn causing less and less pollution (see chapter 3). Moreover, since it is evident that there exist considerable regional disparities among Chinese provinces, there is some concern that instead of the whole of China, relatively poor Chinese provinces are becoming pollution havens. Therefore, it is meaningful to examine the effects of economic growth and international trade on Chinese provincial pollution.

In the existing literature, previous empirical studies only cover a short period of time, normally 10 to 15 years. The problem of short time period empirical studies is that they only capture a fraction of China’s ongoing economic reform process. Since China’s economic reform has lasted a long time period (from 1978 to date), and China’s economic growth has sustained for more than 30 years, empirical studies covering too short time periods are likely to provide biased results, as they focus on specific parts of China’s ongoing economic reform process. Therefore it is meaningful to carry out an empirical study that captures as full as possible a picture of China’s ongoing economic reform process. Our empirical study in chapter 3 contributes to the existing literature by employing a data set covering the period 1985-2010, which captures a longer time span than all existing studies of China's ongoing economic reform process, and the era of China's fast economic and trade growth.

Furthermore, previous empirical studies of Chinese provinces provide ambiguous results on the impacts of economic growth and international trade on China's pollution, but these studies are based on a fraction of our data set. Our empirical work utilising a data set of longer period provides consistent evidence across different pollutants, which is also supported by stylised facts. Lastly, an empirical examination of the impacts of economic growth and international trade on Chinese provincial pollution is helpful for China's national as well as regional environmental policy making.

1.2.3 Sustainable Development

The idea of SD is raised due to the concern about the resource-intensive growth after World War II. According to the United Nations' (UN hereafter) Brundtland Report (1987), SD consists of two main themes: meeting the present needs and protecting the ability to meet future needs. The UN's definition of SD reveals two main threats faced by humanity: poverty and environmental degradation. This section introduces the basic concept of SD and sets up the conceptual background for SD indicators such as Green GDP.

After World War II, some had pessimistic concern over the world economy and worried that the large military spending during the war might drag the world economy back to the Great Depression time. However unexpectedly, the pent-up consumer demand strongly boosted the world economy resulting in fast economic growth in many countries. Especially, West European and East Asian countries performed fast economic growth with almost full employment (Marglin and Schor, 1992). For example, from 1950 to 1969, the United Kingdom (UK hereafter) enjoyed a long period of growth in prosperity with an average annual economic growth rate of over 2.8%, accompanied by an unemployment rate of only 1.6%, which was lower than the average unemployment rates in the period 1921-1938 (13.4%) and 1970-1993 (6.7%)[9]. This period was known as the post-World War II economic expansion period, or the post-war economic boom period.

In the post-war economic boom period, on the one hand rapid economic growth greatly decreased unemployment rate and in turn significantly fostered population growth. The annual number of birth soared up and birth rate grew at a high level. Between 1946 and 1964, over 400,000 babies were born yearly in Canada (Owram D., 1997), and the average annual birth rate was over 2% in the United States (US

[9] Figures are sourced from the UK national statistics and Sloman (2004).

hereafter), which raised the total population of the US by 78.3 million (US Census Bureau, 2008). According to the UK national statistics, this baby boom resulted in a record number of retiring population in the UK in 2012, also bringing over 600,000 people turning 65 each year and in total 3.3 million people reaching state pension age until 2018[10]. On the other hand, this exceptional post World War II economic boom also led to excessive consumption of natural resource causing serious environmental degradation. The electricity consumption in the UK increased by around 150% from 1948 to mid-1960s, in which over 90% of the generating capacity was fired by coal with oil providing most of the reminder (UK government, 2013). In the late 1960s, it was widely believed that the consumption of raw materials and energy was growing almost at the same rate as economic growth (de Bruyn and Heintz, 2002).

The post-World War II economic expansion period showed a prosperity economic development path accompanied by high population growth as well as fast natural resource depletion. This pattern of economic growth raised concern over how long the finite world natural resource could fuel this rapid economic and population growth. To seek an answer for this question, in the book 'The limit to Growth', Meadows et al. (1972) used a world model to simulate the interaction between economic growth, natural resource depletion and pollution. Meadows et al. (1972) found that a balanced development path was possible. This seminal work inspired studies on SD. (Nordhaus, et al., 1992, Pezzey, 1992a, Pezzey and Toman, 2002).

Nowadays, Sustainable Development (SD hereafter) is one of the most popular catchphrases in environmental economics. But what exactly does it mean? This question is still difficult to answer. The difficulty is largely due to the lack of consistency in its interpretation, since SD means different things to different people (detail see Lele, 1991, Hanley et al., 2001, and Redclift, 2005 among others). The most well-known definition of SD is presented by the Brundtland report, which describes it as: "*Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" (World Commissions on Environment and Development, the Bruntland Commission report, the United Nations, 1987).

SD consists of two key concepts: 'needs' and 'limitations'. On the one hand, the 'needs' refer to the essential wants of the world's poor, that is to say, the top priority of

[10] Figures are sourced from The Telegraph (2012), "Record numbers reach retirement age as baby boomers turn 65". http://www.telegraph.co.uk/finance/personalfinance/pensions/9563647/Record-numbers-reach-retirement-age-as-baby-boomers-turn-65.html.

SD is to reduce poverty for the current generation (without compromising the ability of future generations to do the same). On the other hand, the 'limitations' refer to the limits imposed by the state of technology and social organizations on the environment's ability to meet present and future needs. In other words, SD proposes a development path that increases economic prosperity and improves the quality of life for humans at the minimum cost of the natural environment without damaging the prospects of future generations.

Since the Industrial Revolution, human economic activities have been increasingly extracting world natural resources, at the same time excessively generating pollution and causing serious environmental issues (Environmental Protection Agency, 2007). On the one hand, over the past two centuries, it has been seen a growing trend in energy consumption, of which about 80% is sustained by the fossil fuels (Planas, 2012). On the other hand, since the early 20th century, the global air and sea surface temperature has gone up by about 0.8%, in which about two thirds of the increase has been occurring since the 1980s (The National Academies Press, 2011). As reported by the International Panel on Climate Change (IPCC, 2014), it is more than 90% certain that most of global warming is being caused by the increasing concentration of greenhouse gases produced by human economic activities. For example, due to the economic growth between 2000 and 2010, greenhouse gas emissions have been growing by 2.2% per annum, compared with only 1.3% from 1970 to 2000, causing global warming in a faster rate (IPCC, 2014).

Global warming may cause serious environmental disasters. For instance, temperature rise due to global warming accelerates melting of glaciers and ice cap. According to National Aeronautics and Space Administration (NASA, 2014), Arctic ice now is melting at an alarming rate of 9% per decade and Arctic ice thickness has decreased by 40% since the 1960s. Global glacier melting causes sea level rise, loss of coastal wetlands and barrier islands, greater risk of flooding in coastal and riverside communities, and even loss of species. If the current global warming cannot get eased, the US Geological Survey projects that two thirds of polar bears will disappear by 2050 (Ramanujan, 2003).

Not only global warming, economic growth may also deteriorate water resource. Water is an important resource for all species. However, of all the water on earth, 97.5% is salt water and the rest (2.5%) is fresh water, 69% of which is frozen in ice cap, and thus only 30% fresh water is available for consumption, from which 87% is used for irrigation (United States Geological Survey, 2014). These all together leave a very small proportion for human consumption. What makes water resource situation even worse is the pollution from human economic activities, such as pollution from agricultural and industrial production. As by-products of industrial production, chemical waste materials such as asbestos, lead, mercury, and nitrates, seriously contaminate the water resources and are extremely harmful for human life. As a result, one fifth of the world population live in areas of physical water scarcity, one in three people over the world are already facing water shortage, and almost one quarter of the world's population live in developing countries that lack the necessary infrastructure to use water from available rivers and aquifers (United States Geological Survey, 2014).

It may be worth noting that the UN's definition of SD is an opportunities-based view of SD[11], because the UN's definition implies that a sustainable state is one in which resources are managed so as to maintain production opportunities for the future. This is to say, the UN's definition of SD considers the means that are available to society to generate well-being or consumption: its capital. In the broad sense, capital may be categorised into four different forms: natural capital, physical capital, human capital and intellectual capital. Natural capital (K_N) comprises all gifts of nature, such as aquifers and water systems, fertile land, crude oil and gas, forests, fisheries and other stocks of biomass, genetic material, and the earth's atmosphere itself. Physical capital (K_P) includes plants, equipment, buildings and other infrastructure, accumulated by devoting part of current production to capital investment. Human capital (K_H) refers to stocks of learned skills, embodied in particular individuals, which enhance the productive potential of those people. Intellectual capital (K_I) refers to disembodied skills and knowledge. Intellectual capital comprises the stock of useful knowledge, which we might otherwise call the state of technology. These skills are disembodied in that they do not reside in particular individuals, but are part of the culture of a society. They reside in books and other cultural constructs, and are transmitted and developed through time by social learning processes. The sum of physical, human and intellectual capital is also known as the human-made capital ($K_M = K_P + K_H + K_I$). Thus the total stock of capital may also be seen as consisting of two parts: natural and human-made capital. (Perman, et al., 2003).

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[11] Broadly, economists' view on the SD path for an economy over time may be divided into two groups: outcome approach and opportunity approach. The outcome approach provides an ends-based (utility/consumption-based) definition of SD, which defines a sustainable state is one in which utility/consumption is non-declining over time. Whereas the opportunity approach proposes we should pass on the future generations at least as much capital as we have, so that they have no less opportunity than us to be happy. Since our focus is on the opportunities-based view of SD, for saving space we are not discussing the ends-based definition of SD in this chapter. Detail discussions of ends-based definition of SD can be found in Pezzey (1992b), Pezzey (1997), Hanley et al. (2001), and Perman et al., (2003).

A distinction is often made between “weak sustainability” and “strong sustainability”. The main difference between these two economic paradigms of SD is the substitutability between natural and human-made capital (Neumayer, 1999). “Weak sustainability” requires the total capital stock to be non-declining over time implying natural capital can be substituted by human-made capital. According to “weak sustainability”, it does not matter that natural capital is reduced, such as non-renewable resources depletion and environmental degradation, as long as the reduction of natural capital is compensated by the increase of human-capital, such as increase in machineries, roads and ports. In other word, “weak sustainability” assumes natural capital is regarded as being essentially substitutable in the production of consumption goods (Solow, 1974a, 1974c, 1986, 1993a, and 1993b, and Hartwick, 1997, 1978a, 1978b, 1990, and 1993). Although historical experience does tend to support the view of weak sustainability that the accumulation of human-made capital can offset the problems arising from natural capital/resources depletion, some argue that services provided by the natural capital/resources are not compensable by human-made capital. For instance, it is possible to use human-made capital to provide necessary life-support service such as temperature control, and breathable air, etc., but this is only at a small scale so far, and it has yet to be demonstrated that it is feasible at a large scale, such as billions of humans (Perman, et al., 2003). In contrast, “strong sustainability” derives primarily from the view that depletion in natural resource cannot be substituted with increase in human-made capital, thus it requires non-declining natural capital stock.

Measuring SD is especially difficult for developing countries such as China, at the same time measuring SD is vitally important in guiding developing countries’ economic development policies (detailed in chapter 4). That is why Chinese government urgently wants to use a new indicator to replace GDP as a measure of China’s economic development. China’s Green GDP project has been terminated due to data issues, we propose a new approach in chapter 4 to confront China’s Green GDP problem and create a new set of Green GDP data for Chinese provinces. Utilising our Chinese provincial Green GDP data, we investigate the relationship between trade and Green GDP to fill in the gap that there is no any existing literature in this area (detailed in chapter 4).

1.2.4 Welfare and economic growth: Threshold Hypothesis (TH) and Contracting Threshold Hypothesis (CTH)

The Environmental Kuznets Curve (EKC) hypothesis presumes an inverted U shape relationship between income and environmental degradation. That is to say, as income goes up, environmental degradation first increases up to a point, the turning point, after which environmental quality improves as income grows. Although the existing theoretical EKC studies have explained causes of this inverted U shape relationship from various aspects, the enormous EKC empirical studies still cannot reach a consensus.

If the EKC exists, the relationship between income and the environment may not be a straightforward linear relationship, instead it may be a nonlinear one, and therefore the relationship between income and sustainable income may be nonlinear too. This assertion bases on assumptions that environmental degradation and environmental quality are negatively correlated, environmental quality and quality of life are positively related, and quality of life can be measured by Green GDP. However these three assumptions may not be valid in some circumstances. Firstly for many types of pollution, it is true that pollution and environmental quality are related negatively, but there are some exceptions. If the environmental damage caused by environmental degradation is irreversible, then income growth may reduce environmental degradation and help to protect the environment, but may not significantly improve environmental quality. For instance, the once released to the atmosphere some greenhouse gases can stay there for more than 100 years. Moreover, some damages to the ecosystem such as extinction of species are irreversible. Secondly, environmental quality and quality of life are positively related if people derive utility directly from the environment. This assumption is also conditional on the other determinants of well-being. Lastly, quality of life may be better measured by ISEW and GPI, which account for social as well as environmental costs and benefits to people; whereas, SNDP and CGGDP only consider environmental costs. Because the assertion that the income and sustainable income relationship may be nonlinear, bases on above debatable assumptions, it is interesting to carry out empirical studies to investigate the relationship between income and sustainable income.

After carrying out a study for 19 rich and poor countries, Max-Neef (1991) has detected among people in the rich countries a growing feeling that they are part of an overall deteriorating system that affected them both at the personal and collective levels. Therefore, Max-Neef (1995) proposes a “Threshold Hypothesis” (TH hereafter) arguing for every society there seems to be a period in which economic growth (as conventionally measured by GDP) brings about an improvement in the quality of life (as indicated by Green GDP), but only up to a point – the threshold point – beyond which, if there is more economic growth, quality of life may begin to deteriorate.

Empirical evidence supporting TH has be found in important publications such as Max-Neef (1995), Jackson and Stymne (1996), Lawn (2005 and 2006a), Lawn and Clarke (2010). In all existing studies, TH is empirical tested through plotting GDP and Green GDP data against time as in figure 1.5. After plotting GDP and Green GDP for six developed countries: Austria, Germany, the Netherlands, Sweden, the UK, and the US, figure 1.5 shows that Green GDP in every country has a threshold point, after which further rises in GDP decrease Green GDP. TH implies there is an optimal level of income, after which further economic growth incurs more costs than benefits, therefore although income may still grow, the welfare actually declines.

Lawn and Clarke (2010) develop TH further by arguing that there is not only a threshold point at which the costs of GDP growth outweigh the benefits, but also this threshold point appears to be contracting (i.e. occurring at a much lower per capita level of GDP). This hypothesis is named as the “Contracting Threshold Hypothesis” (CTH). In a study of Green GDP in Asia-Pacific region, Lawn and Clarke (2010) find that though per capita GDP is growing in Asia-Pacific region, the Green GDP in every country appears to have a threshold and Green GDP in developed countries reaches a higher threshold point earlier than the developing countries. For instance, Green GDP in Australia, New Zealand and Japan has peaked respectively at $21,583.3 in 1974, $16,040.0 in 1981, and $14,075.2 in 1998; whereas, Green GDP in India, China, Thailand and Vietnam has reached a threshold at $1,561.7 in 2003, $1,538.8 in 2002, $3,492.3 in 2001, and $1,259.4 in 2003, respectively (table 1.1). Thus not only Green GDP in developed countries has reached a threshold point that is higher than developing countries, but also Green GDP in developed countries has reached the threshold point chronologically earlier than developing countries in Asia-Pacific region.

Intuitively, CTH may be explained in many ways including the concept of “full” world and Pollution Haven Hypothesis (PHH from now on). As human economy evolves, economic growth incurs increasing population and rising physical transformation of natural capital to human-made capital. At the same time, the world has been transformed from relatively “empty” human economics activities to relatively “full” human economics activities. Thus the “empty” world refers to relatively less human economic activities, whereas “full” world refers to relatively more human economic activities. Daly (1991, 1996 and 1999) point out that this evolution of the human economy has passed from an era in which human-made capital was the limiting factor to an era in which remaining natural capital has become the limiting factor. Therefore economic growth late-comers face substantially higher marginal cost for an increment of GDP growth, because in the “full” world, natural resources are scarcer and the environmental assimilation power is weaker. As a result, economic growth early-birds reach higher Green GDP peaks and earlier, whereas economic growth late-comers reach the threshold with lower Green GDP but later.

Moreover, CTH may also be explained from the PHH as put forward by Lawn and Clarke (2010). PHH asserts that the comparative advantages between trading partners are determined by the relative stringency of environment regulations (see detail about PHH in chapter 2). Since economic growth late-comers are developing countries with relatively more lenient environmental regulations, they are more likely to become pollution havens. Thus the late-comers’ economic growth is at the cost of their environment, so their economic development is unstainable and leads to a later and lower Green GDP threshold point than early-birds. This argument is supported by the experience of economic growth in Japan and Australia. Total environmental cost of economic growth in Japan has declined over time as well as total environmental cost as a percentage of real GDP, while Australia’s total environmental cost as a percentage of real GDP has also declined in the period 1967-2006 (Lawn and Clarke, 2010).

However, as many other hypotheses, the TH is not free of critiques. Neumayer (2000) point out that proponents of Green GDP such as ISEW and GPI, consider their results too easily as evidence for the TH, since the calculation of Green GDP indices involves many assumptions. Thus the widening gap between GDP and Green GDP may be the artefact of highly contestable methodological assumptions. After studying the ISEW and GPI in four developed countries: the Netherlands, Sweden, the UK and the US, Neumayer (2000) finds evidence that two assumptions are significantly contributing the widening gap between GDP and Green GDP, they are the assumption of a cost escalation factor in the valuation of non-renewable resources depletion, and the assumption of cumulative long-term environmental damage.

In most Green GDP indices, non-renewable resources depletion is an indispensable item. Since extraction of non-renewable resources cannot be prolonged forever and is therefore unstainable into the indefinite future, SD (following strong sustainability, which implies that some elements of natural capital are irreplaceable.) requires that the non-renewable resources depletion has to be replaced by renewable resources substitution, which in turn incurs the replacement cost. A cost escalation factor is needed in the replacement cost valuation method of non-renewable natural resource depletion to account constantly increasing replacement costs (Cobb and Cobb, 1994). Neumayer (2000) shows that if instead replacement costs are not assumed to escalate by 3% per annum[12], but assumed to remain constant, then non-renewable resources depletion no longer gives rise to the TH.

Another cause of TH may be due to the assumption of cumulative long-term environmental damage in the Green GDP indices. Because some environmental damage such as climate change, is believed to be a result of accumulated environmental damage over time. ISEW and GPI often include an item to value accumulated environmental damage. Following Daly et al. (1989) and Cobb and Cobb (1994), most studies opt for an accumulation approach, in which environmental damage in one period is set aside to accumulate and contribute for environmental damage in future periods. This accumulation approach is obviously incorrect, since the total future environmental damage is already included in marginal social cost of current environmental damage. Thus letting the environmental damage costs accumulate over time is not only self-contradictory, but also causes multiple counting problems (Atkinson, 1995, and Neumayer, 2000). If instead accumulated environmental damage, marginal social costs are opted for valuing environmental damage, even with increasing marginal social costs, the threshold effect will still fail to materialise (Neumayer, 2000).

One obvious gap in the TH and CTH literature is that all existing studies are at national level, but if there is TH and CTH, we should be able find evidence from subnational level such as provincial level. Chapter 4 fills this gap by studying the relationship between GDP and Green GDP at China’s provincial level.

[12] A cost escalation factor of 3% per annum is proposed by Cobb and Cobb (1994), and widely used in ISEW and GPI calculation for Scotland, Australia, the UK and the US among others.

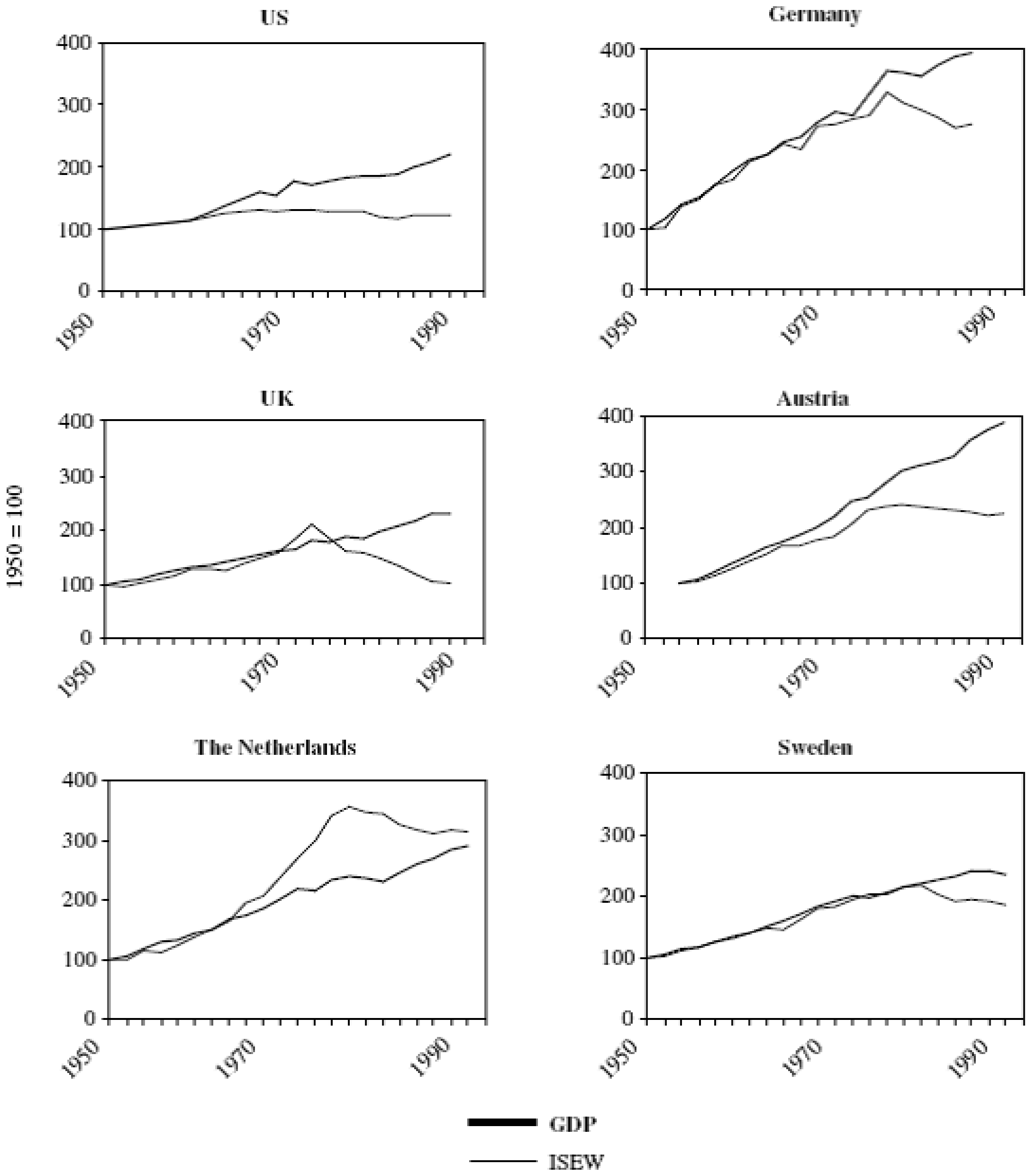
Per capita GPI and per capita GDP of the seven Asia-Pacific case study countries.

	Australia		New Zealand		Japan		India		China		Thailand		Vietnam	
Year	p.c. GPI	p.c. GDP	p.c. GPI	p.c. GDP	p.c. GPI	p.c. GDP	p.c. GPI	p.c. GDP	p.c. GPI	p.c. GDP	p.c. GPI	p.c. GDP	p.c. GPI	p.c. GDP
1967	19,842.4	14,518.8	–	–	–	–	–	–	–	–	–	–	–	–
1968	20,167.3	14,999.3	–	–	–	–	–	–	–	–	–	–	–	–
1969	20,275.1	15,722.0	–	–	–	–	–	–	–	–	–	–	–	–
1970	20,590.1	16,518.5	13,108.8	12,826.8	5143.1	12,550.0	–	–	860.8	538.9	–	–	–	–
1971	20,516.1	16,445.6	13,893.8	13,068.7	6208.3	12,892.8	–	–	863.5	561.4	–	–	–	–
1972	20,787.6	16,790.1	14,026.2	13,164.2	7337.5	13,784.4	–	–	870.6	569.8	–	–	–	–
1973	21,233.4	16,980.8	14,533.6	13,502.9	7949.2	14,690.0	–	–	883.7	600.8	–	–	–	–
1974	**21,583.3**	17,386.0	13,947.9	14,215.9	7232.4	14,335.7	–	–	866.0	603.4	–	–	–	–
1975	21,081.8	17,378.8	14,969.1	14,529.8	7342.7	14,583.3	–	–	8 66.2	644.8	1633.2	2278.1	–	–
1976	20,649.1	17,670.7	15,266.4	14,760.9	7761.8	15,023.5	–	–	856.6	625.7	1771.5	2447.8	–	–
1977	19,981.8	18,077.7	15,100.9	14,758.4	7963.0	15,538.0	–	–	868.7	664.4	1629.7	2632.4	–	–
1978	19,256.4	18,027.7	15,281.1	14,340.7	8568.8	16,202.3	–	–	868.7	732.2	1708.7	2833.5	–	–
1979	18,636.3	18,580.0	15,714.0	14,753.9	8318.2	16,948.7	–	–	863.5	777.5	2047.4	2924.0	–	–
1980	18,255.6	18,929.2	15,312.3	15,117.5	7966.7	18,231.8	–	–	870.8	828.3	2194.4	3023.2	–	–
1981	18,116.9	19,270.8	**16,040.0**	15,165.8	8503.2	18,560.9	–	–	877.1	859.4	2171.0	3140.6	–	–
1982	17,852.7	19,540.3	15,623.0	15,792.3	8824.1	18,829.9	–	–	901.5	923.1	2144.7	3243.0	–	–
1983	17,620.9	18,816.7	15,165.2	15,775.1	9482.4	18,992.5	–	–	983.8	1010.2	2201.5	3377.7	–	–
1984	17,616.0	19,462.4	14,487.8	16,560.1	10,272.4	19,548.7	–	–	994.8	1148.7	2195.6	3496.7	–	–
1985	17,732.6	20,227.4	14,510.1	17,296.7	10,914.8	20,509.1	–	–	1024.7	1285.4	2117.3	3573.5	–	–
1986	17,389.9	20,822.6	14,879.3	17,143.9	11,330.5	21,192.5	–	–	1037.0	1377.0	2082.5	3687.8	–	–
1987	16,675.0	21,003.9	14,510.7	17,590.2	11,632.8	21,832.4	1280.0	1618.2	1038.4	1511.5	2127.9	3970.9	–	–
1988	17,169.6	21,729.3	14,192.4	17,748.1	11,677.6	23,208.9	1298.5	1740.0	1104.5	1656.1	2212.6	4409.5	–	–
1989	16,988.3	22,155.4	14,175.2	17,660.9	11,988.2	24,367.4	1222.5	1813.6	1048.9	1698.4	2155.2	4865.1	–	–
1990	17,093.2	22,689.7	13,501.6	17,566.0	12,275.7	25,474.6	1295.1	1879.9	1029.5	1737.8	2153.5	5368.5	–	–
1991	16,978.8	22,258.7	12,835.7	17,132.5	12,522.4	26,273.3	1179.1	1859.1	1056.4	1873.2	2428.9	5760.7	–	–
1992	16,917.7	22,009.1	14,185.4	17,086.0	13,120.6	26,452.4	1287.4	1918.8	1072.7	2114.6	2502.6	6137.0	996.5	1239.9
1993	16,551.4	22,590.9	9840.2	17,899.0	13,484.3	26,312.9	1237.2	1969.2	1081.2	2383.3	2742.3	6581.1	1034.5	1317.1
1994	16,721.6	23,270.9	11,878.8	18,570.0	13,309.6	26,424.6	1340.7	2076.4	1132.1	2665.5	2853.8	7080.3	1096.3	1409.5
1995	16,861.7	24,022.5	12,130.3	19,025.9	13,659.6	26,887.5	1366.9	2191.6	1226.6	2925.1	2921.0	7687.0	1160.0	1518.9
1996	17,064.9	24,684.7	12,963.0	19,506.6	13,439.0	27,772.4	1402.8	2306.1	1353.4	3184.2	3095.9	8051.9	1201.6	1634.4
1997	17,071.8	25,367.8	10,962.0	19,958.6	13,724.1	28,192.0	1350.5	2364.2	1421.5	3445.5	3209.9	7850.0	1177.6	1740.3
1998	17,051.2	26,230.0	11,857.1	20,057.9	**14,075.2**	27,806.4	1406.2	2459.7	1498.8	3680.5	3027.4	6950.8	1166.7	1812.5
1999	17,305.5	27,273.8	14,237.0	20,963.2	13,539.3	27,743.4	1478.1	2587.4	1498.4	3928.0	3168.6	7235.6	1107.8	1870.8
2000	17,573.2	28,021.7	14,208.3	21,344.0	13,427.0	28,336.9	1439.1	2639.1	1481.5	4225.8	3222.0	7301.7	1109.7	1971.0
2001	17,711.1	28,184.8	14,205.8	21,821.5	13,408.3	28,313.5	1517.1	2726.1	1531.9	4544.8	**3492.3**	7372.7	1102.5	2078.8
2002	17,949.1	28,907.1	12,910.8	22,457.5	13,518.0	28,208.5	1460.3	2789.6	**1538.8**	4926.5	3439.1	7665.7	1176.7	2196.9
2003	17,579.7	29,470.7	13,925.0	22,978.9	13,954.7	**28,525.3**	**1561.7**	**2981.5**	1490.3	5386.7	3253.9	8101.5	1216.8	2323.9
2004	18,185.1	30,331.0	14,286.0	23,413.1	–	–	–	–	1525.2	5896.0	3173.7	**8494.5**	**1259.4**	**2470.5**
2005	18,101.6	30,762.7	14,461.7	**23,537.3**	–	–	–	–	1511.9	**6459.2**	–	–	–	–
2006	18,161.2	**31,218.8**	–	–	–	–	–	–	–	–	–	–	–	

All currencies valued in International Dollars (2004 prices).

Table 1.1: Contracting Threshold Hypothesis
Sourced from Lawn and Clarke (2010).

AN ASSESSMENT ON ISEW, GPI, AND SNBI 187



Comparison of GDP and ISEW for the US, Germany, UK, Austria, The Netherlands, and Sweden (Jackson, T. and Stymne, S. (1996) *Sustainable Economic Welfare in Sweden: A Pilot Index 1950–1992*, Stockholm Environment Institute, The New Economics Foundation).

Figure 1.5: Threshold Hypothesis

Sourced from Lawn (2005).

It may be difficult to distinguish GDP and ISEW in this figure, the key feature is that the line first goes up and then goes down after a peak is ISEW.

Therefore the last question this thesis addresses is:

(3) Is international trade good for China’s sustainable development?

Because sustainable development proposes a development that meets the needs of the present while protecting the ability to meet future needs, conventional economic performance indicators such as GDP are not appropriate indicators for measuring human well-being or sustainable development. Green GDP measures that adjust GDP with environmental costs represent one step further towards an appropriate measure of sustainable development. Giving significant regional disparities, Green GDP at Chinese provincial level is particularly useful for Chinese government’s sustainable development policy design, because to achieve sustainable development, Chinese government needs to take into account of China’s growing provincial economic gaps (see chapter 4). To our knowledge, this thesis is the first study to compute Chinese provincial Green GDP.

Moreover, since international trade is believed to promote economic development and in turn raise income on the one hand, but stimulate energy consumption and in turn cause pollution on the other hand, it is therefore not clear what the net effect of international trade on sustainable development is. This question is particularly interesting in the case of China, due to China’s unneglectable influence on the world economy and trade. To our knowledge, there is only one existing empirical study on the relationship between trade openness and Green GDP, Talberth and Bohara (2006). Utilising national Green GDP of mainly developed countries, Talberth and Bohara (2006) find a negative nonlinear relationship between trade openness and Green GDP. We provide a complementary study of Talberth and Bohara (2006) by focusing on one developing country: China. Our empirical study on the relationship between China’s international trade and Green GDP is helpful for China’s trade policy as well as sustainable development policy making.

In sum, the purpose of this thesis is to empirically investigate (i) the broad validity of the EKC in open economies using BASIC country data to explore the causal interrelationships between growth, the environment and trade; (ii) the validity of the FEH and PHH using provincial Chinese data to explore channels thru which trade might impact the environment; (iii) the validity of the TH and CTH using provincial Chinese data to construct measures of “green” GDP. As it is, material in $1.2 is simply repeated in later chapters where these concepts are discussed at greater length.

1.3 Thesis Structure

The rest of thesis is organised as follows:

Chapter 2 answers question (1) how import is the impact of economic growth and international trade on BASIC countries' environment? Existing literature about BASIC countries provides mixed results for causality between growth, trade and pollution, and evidence of various EKC shapes, and also no previous study addresses trade effects on environment in BASIC countries, because most empirical studies focus on investigating international trade effects using developed countries data. This thesis contribute to existing literature by filling these gaps. To do so, we first investigate the causality between growth, trade and pollution, then empirically test if EKC exists in each BASIC countries for global as well as local pollutions, and lastly address trade effect on pollution and EKC. Our results suggest that (1) economic growth causes pollution, suggesting that environmental degradation is closely associated with economic growth as argued by the EKC hypothesis; (2) there is inter-country heterogeneity in the shape and turning point of the EKC in the BASIC countries; and this inter-country heterogeneity also varies by different environmental degradation indicators; (3) we empirically show that international trade has relative small effects on pollution and plays little role in EKC shaping, indicating that international trade is not causing pollution in BASIC countries.

Chapter 3 tries to answer question (2) what is the environmental impact of China's notable economic growth and international trade, in particular, are some specific Chinese provinces becoming pollution havens? In previous studies, there are very few studies addressing PHH and FEH at subnational level, and empirical studies about China provide mix results, and also there is no study using FDI inflows as a measure of openness level. This thesis fills these gaps by examining the effect of China's trade openness and FDI inflows on Chinese provincial pollution. Our main contributions are as follows: (1) previous studies using a fraction of our data set provide ambiguous results. In contrast, we utilise the full data set and find clear evidence that trade openness and FDI inflows are good for the environment (reducing pollution) in Chinese provinces, indicating international trade does not lead to Chinese provinces becoming pollution havens. (2) Existing theoretical literature presumes that high capital intensity indicates high pollution intensity, and many previous empirical studies usually support this assumption. However, in our study of Chinese provinces, we find evidence contrary to this assumption, that high capital intensity does not necessarily mean high pollution intensity, and therefore our work suggests that it is improper to use capital intensity as a proxy measure of pollution intensity.

Although Levinson and Taylor (2008) argue that environmental regulations should be treated as endogenous variables in PHH and FEH empirical studies, from our results in Chapter 2, we find that environmental regulations (as proxied by GDP due that environmental regulations are believed to be positively related to GDP) can be treated as if they are exogenous. Moreover environmental regulations are exogenous in developing countries such as China, because firstly over our sample period China's environmental policies are consistent not different across provinces indicating all Chinese provinces are facing the same environmental regulations regardless their economic development, secondly there is no evidence showing economic development in Chinese provinces affects central government's environmental policy making (Zhang 2014), last but not least, it is evident that the implementation power rather than environmental regulations is key to China's regional pollution (Zhang 2014).

Furthermore, there is no omitted variables problem in our estimation, because our omitted test results suggest there is no significant omitted variables problem, and many empirical studies support our finding such as Zhang and Fu (2007). This is not difficult to understand, as discussed in many newspapers, two main factors affecting China's environment are economic growth and international trade.

Chapter 4 addresses question (3) is international trade good for China's sustainable development? So in Chapter 4 we study the effects of international trade on Chinese provincial Green GDP. Existing literature only computes Green GDP at China's national level. There is only one existing study investigating the relationship between trade and Green GDP, which covers a sample of OECD countries. Also there is no study testing TH or CTH at subnational level. This thesis fills these gaps by building a data set of China's provincial Green GDP, using it to investigate the relationship between trade and Green GDP, and testing TH and CTH at subnational level at China's provincial level. Our main contributions are as follows: (1) we provide a discussion on China's Green GDP calculation and compute Chinese provincial Green GDP following four different approaches for the period 1985 to 2010. Using our Chinese provincial Green GDP, (2) we test the threshold hypothesis (TH) and contracting threshold hypothesis (CTH), and (3) carry out an empirical study on the relationship between China's Green GDP and trade openness. Our estimation results consistently suggest a positive non-linear relationship between trade openness and Green GDP; hence, we propose a threshold hypothesis between trade openness and sustainable development as follows:

The relationship between trade openness and sustainable development are nonlinear and has different shapes in developed and developing countries. In developed countries, the relationship between trade openness and sustainable development has a U shape; whereas in the developing countries, the relationship between trade openness and sustainable development has an inverted U shape.

Chapter 5 presents concluding remarks for the whole thesis. Section 5.1 summarises the empirical findings from three chapters above, and discusses policy implications. Section 5.2 points out limitations of this thesis and recommends possible future research as extensions to this study.

Chapter 2: Growth, Trade and the Environment in Four Developing Countries

2.1 Introduction

The four large developing countries, Brazil, China, India and South Africa, share a similar pattern of rapid economic growth, high degrees of international openness, and serious environmental degradation; they also often share a common stance on many environmental issues as mentioned in the mass media as well as in academic discussions. In this chapter, we investigate the relationship between economic growth, international trade and environmental degradation in these four developing countries. According to the Environmental Kuznets Curve (EKC hereafter) hypothesis, the Pollution Haven Hypothesis (PHH hereafter) and the Factor Endowment Hypothesis (FEH hereafter), economic growth and international trade may have positive as well as negative effects on the natural environment. On one hand, economic growth increases the size of the economy, which in turn generates pollution (scale effect). International trade may stimulate economic growth, and thus leads to pollution. On the other hand, economic growth may be also good for the environment, since it may change the economic structure from dirty industries to clean industries, and foster technology improvement. Meanwhile, international trade may promote these positive effects on the environment through reinforcing economic structural changes and increasing technology spillover. As a result, what are the net effects of economic growth and international trade on the natural environment becomes an empirical question.

In the relationship between growth, trade and the environment, causality is the key. Existing theoretical models and hypotheses imply causalties of different directions between growth, trade and environment. For instance, EKC implies a unidirection causality from growth to pollution, PHH indicates causalities between trade and pollution, and Growth-led Trade hypothesis (GTH) suggests a unidireciton causality from growth to trade. Investigating the causality between growth, trade and the environment helps us to form the estimation function for our data sample.

In order to address these questions, we carry out a series of empirical studies using a data set of four developing countries, Brazil, China, India and South Africa by (1) conducting a causality study to examine the Granger-causal relationship between economic growth, international trade and environmental degradation, this will shed light on the EKC hypothesis, PHH and FEH which imply causal relationships between economic growth, international trade and environmental degradation; (2) investigating the environmental impact of economic growth through testing the well-known EKC hypothesis; (3) examining the international trade effects on environmental degradation and the shape of EKC.

Our main findings are as follows. (1) We find evidence that economic growth causes pollution, suggesting that environmental degradation is closely associated with economic growth as argued by the EKC hypothesis. (2) We also find evidence that there is inter-country heterogeneity in the shape and turning point of the EKC in the BASIC countries; and this inter-country heterogeneity also varies by different environmental degradation indicators. (3) Our empirical study shows that international trade has relatively small effects on pollution and plays little role in shaping the EKC. In sum, our finding suggests that although economic growth in these four developing countries may not be compatible with sustainable development, the latter may not be hampered by international trade.

The remainder of this chapter is organised as follows. Section 2.2 introduces the background information for our study, followed by a brief literature review in section 2.3. Section 2.4 outlines our methodology and describes the data. Section 2.5 presents our results, and Section 2.6 concludes.

2.2. Background of study

This section provides background information about four developing countries, Brazil, China, India and South Africa. We first briefly review their economic history after World War II. Then we discuss environmental issues in these developing countries. Lastly, we discuss economic growth, trade and pollution in these developing countries for the period 1960-2012.

2.2.1 A brief review of the economic history in four countries

This section briefly reviews the post-World War II economic development in the four developing countries, Brazil, China, India and South Africa. It mainly covers the period from the 1950s to 2012, with focus on national economic growth, economic structure and trade. Political events and government policies are also discussed but with the emphasis on their impacts on the respective national economy.

2.2.1.1 Brazil

After World War II, a socioeconomic transformation rapidly took place in Brazil. This transformation speeded up Brazil's industrialisation process and stimulated its economic growth. Brazil's economic growth was greatly driven by the growth of its industrial sector. From 1950 to 1960, Brazil's industrial sector posted an average annual growth rate of over 9%, compared with only 4.5% for its agricultural sector. As the engine of growth, this rapid growth in industrial sector significantly stimulated Brazil's

GDP growth, which achieved an average annual growth rate of over 7%. Meanwhile, the structure of Brazil's industrial sector also experienced considerable change. Traditional industries, such as textiles, food products, and clothing, declined, while transport equipment, machinery, electric equipment and appliances, and chemical industries, expanded (Ellis, 1969). In 1960, Brazil's agriculture sector, industrial sector and service sector accounted for 20.59%, 37.07% and 42.43% of its total GDP respectively, while within the industrial sector, the manufacturing sector accounted for 29.61% (World Bank, 2014). However in this period, Brazil's economic growth largely increased its imports, and in turn worsened its balance of payments deficits. To mitigate the balance of payments problem, the Brazilian government implemented an Import Substituting Industrialization (ISI) policy, such as introducing import licensing, tariffs, quotas, and prohibitions. As a result, Brazil's exports and imports reduced sharply, while the growth rates of its industrial sector and the economy slowed down to 3.9% and 4% respectively in the early 1960s (Colistete, 2009).

To boost up the economy, the Brazilian government introduced a string of economic reforms, which created very good conditions for economic growth in the late 1960s. From 1968 to 1973, the economy recovered rapidly and its average annual economic growth rate jumped to 11.1%, which again was greatly attributable to the rapid growth of its industrial sector at an annual rate of 13.1%. This rapid growth encouraged Brazil's exports and imports, which together led to a significant increase in its trade openness ratio (sum of exports and imports divided by GDP) from 12.61% to 17.77% (World Bank, 2014). Though troubled by the 1973 oil crisis, Brazil continued its rapid economic growth in the 1970s. Brazil's economic structure also changed significantly: the GDP share of its industrial sector expanded to 43.83%, with the manufacturing sector share reaching 33.49%, whereas the agriculture sector share shrank by about half to only 11.01% (World Bank, 2014). However, Brazil's economic growth in this period was achieved at the cost of raising its foreign debt level, because its overvalued currency undermined the exports. Thus, Brazil's imports peaked to a record high of 13.88% of GDP in 1974, which led its total trade openness ratio to a spike of 21.90%, but again further worsened its balance of payments problem (Baer, 2008).

Thus, in the 1980s, because of the 1979 oil shock and the rise in the world interest rate, Brazil's foreign debt piled up rapidly, aggravating its balance of payments problem and inducing a fiscal crisis. Brazil's inflation rate had run at an annualised rate of 100% the until mid-1980s, then it shot up to more than a 1000% in 1990, and peaked at a record high of 5000% in 1993 (Baer, 2008). This caused a rapid drop in Brazil’s industrial output, especially in its manufacturing sector. From 1980 to 1993, the manufacturing GDP share fell from 33.49% to 24.95%. Meanwhile, Brazil’s economic growth almost stagnated at an average annual growth rate of only 2.9%, and its per capita income declined by 4.4% over the period of 1980-1993. Also the fiscal crisis generated huge negative effects on Brazil’s trade. Brazil’s imports declined to only 5.46% of GDP, less than a half of that in 1980. Its exports first went up to 13.55% of GDP in 1984, due to the government’s “Export Promotion Policy”, but then declined slowly to 8.93% in 1989 (Shapiro, 1997, and World Bank, 2014).

To stabilise the economy and bring down inflation, the government introduced the Plano Real ("Real Plan") in 1994. The Plano Real sought to break down the inflation expectation by pegging the Brazilian currency “Real” to the US dollar. As a result, Brazil’s inflation was quickly brought down to single digit annual figures, and its economic crisis gradually faded (Franco, 1997). However, due to the substantial real exchange rate appreciation during the transition phase of the Plano Real, Brazil’s goods were still more expensive than goods from other countries. Thus, Brazil’s exports declined further to only 6.56% of GDP dragging the total trade openness to only 14.9% in a short period just after 1994 (Cardoso, 2009). From then on, Brazil’s exports and imports started to grow steadily. Moreover, after the Plano Real, Brazil’s economic structure has stayed stable with the GDP share of agriculture at 5.80%, service at 66.79%, and industry at 27.41%. The manufacturing sector accounts for about 16.79% of GDP (World Bank, 2014). By 2013, Brazil has become the largest economy in Latin America, the sixth largest economy by nominal GDP and seventh largest by GDP at purchasing power parity (PPP) in the world. Now, the Brazilian economy is also one of the fast growing economies in the world with an annual growth rate of over 5%, and expected to be the fourth largest economy by GDP at PPP in the world by 2050 (PwC, 2013).

2.2.1.2 China

Ravaged heavily by World War II, the Chinese economy started recovery when the Chinese Communist Party (CCP) came to the power in 1949. The government gradually restored economic order, brought down inflation, and nationalised industries and land. These reconstructions provided a viable economic base for China’s economic growth in the early 1950s. In 1953, following the Soviet economic model, the government embarked on the “First Five-Year Plan”, in which top priority was given to the development of industrial sector, especially the heavy industries. Meanwhile, the agriculture sector also underwent extensive changes, including modernisation of agricultural resources and improving the efficiency of farming (Shabad, 1955). Thus, China's industrial output grew rapidly at an average annual rate of 19%, while its agricultural output also grew but only at a low average annual rate of 4% from 1952 to 1957. However, the country soon went into the so called "Great Leap Forward (1958-1960)" movement, in which the economy's productive capacity was stretched beyond the feasible level. As a result, industrial output leapt up by 55%, but agricultural output fell disastrously by 14% and 13% in 1959 and 1960, respectively (MacFarquhar, 1987).

To mitigate the damage done to the economy by the "Great Leap Forward (1958-1960)", the government sharply reoriented its policies to place greater emphasis on agriculture than industry. This was known as the "Agriculture First" policy in the early 1960s. A number of policy measures were implemented to provide greater support for the agriculture sector, such as cutting the agricultural tax, raising the prices of agricultural products, and increasing the supply of chemical fertilizers. During the "Agriculture First" period, both the industrial and the agriculture sectors grew steadily with an average annual rate of 10.6% and 9.6% respectively, even surpassing the peak level of output in the Great Leap Forward period (Robert, 1987). But soon the Cultural Revolution (1966-1976) took place, during which economic growth was stagnated.

In 1978, the Chinese government decided to undertake a gradual but fundamental economic reform. The main purpose of this reform was to substantially increase the role of market mechanism. The Chinese economy has since been gradually transformed from a centrally planned economy to a market-oriented economy, known as "socialism with Chinese characteristics". This reform was speeded up by the "southern tour talks" from Deng Xiaoping in 1992, in which Deng reaffirmed the government's commitment to further reform. Thus after 1992, China began accelerating its reform process, especially the privatisation process. In the mid-1990s, the GDP share of private sector in Chinese economy exceeded the public sector for the first time. Since then, the Chinese economy has performed remarkable growth. From 1990 to 2005, aggregate GDP rose over tenfold, whilst per capita GDP increased from 2.7% to 15.7% of US GDP per capita, and from 53.7% to 188.5% of Indian GDP per capita (Herston et al., 2008). Meanwhile, China's economic reform has also led to great changes in its economic structure. From 1978 to 2011, the contribution of agriculture to GDP reduced significantly from around 30% to only 10%, accompanied by a sharp rise in share of the service sector from about 24% to 43.32%. The share of industrial sector remained almost constant at around 45%, which the share of manufacturing declined from 40.47% to 29.25% (World Bank, 2014).

In the same period, stimulated by rapid economic growth, China's trade openness ratio also shot up sharply from only 5.31% (1970) to 58.71% (2011), with imports increasing from only 2.70% (1991) to 27.32% (2011) of GDP (World Bank, 2014). Most notably, in just about 15 years (1990-2005), China's exports increased by 25 times in real terms, from US$ 35.9 billion to US$ 897.7 billion (in constant 2000 dollar), which accounted for 25% of the world total exports of that year (Hanson and Robertson, 2008). By 2013, China has become the second biggest economy in the world by both nominal and purchasing power parity GDP just after the United States, also one of the world's fastest-growing major economies with an average annual growth rate over 10% for more than three decades (1980s to 2010s, figure sourced from then IFM), and it is expected to be the largest economy by GDP at PPP in the world by 2050 (PwC, 2013). At the moment, China is the world's largest manufacturing economy, the largest exporter and second largest importer.

2.2.1.3 India

After gaining independence in 1947, the Indian government decided to have a planned economy and embarked upon a series of reforms, known as the "Socialist reforms". Through these reforms, the government intended to follow the example of the Soviet Union to promote economic growth via state controlled industrialization, active intervention, mandatory licensing of all businesses and introducing high tax to profitable businesses. These policies significantly discouraged investment and savings in the private sector, and resulted in a less dynamic economy. As a result from the 1950s to 1980s, Indian economy stagnated at a low annual growth rate of around 3.5 %, while its per capita income grew at an even lower rate of 1.3% every year. This was known famously as the "Hindu rate of growth" (Ahluwalia, 1995). Meanwhile, the structure of Indian economy remained almost unchanged: the GDP share of agriculture sector was around 41.62%, service sector around 38.02%, and industrial sector around 20.35%, with the contribution of manufacturing around 14.10% of GDP (World Bank, 2014). In terms of trade policy, the government promoted the protectionism and import substitution policies by utilizing import substitution, introducing import quotas and rising significantly trade tariffs. As a result, India's trade openness ratio kept almost constant at about 11% for almost three decades from 1960s to 1990s (Frankena, 1974).

In 1991, India was facing a serious balance of payments crisis and had to agree to a bailout deal with the IMF, who urged India to undertake a series of structural reforms. Then, in the summer of 1991, India started its economic liberalisation, which has brought huge changes to the Indian economy. During the economic liberalisation, Indian government sharply switched its role from planning the economy to facilitating and regulating the economy, by giving more freedom to entrepreneurs, freeing up the private sector, and opening up the economy (Kotwal et al., 2011). As a result, GDP and per capita income grew at annualised rates of 6.6% and 7% respectively from 1990 to 2010 (Ministry of Statistics and Programme Implementation, India). Meanwhile, India's economic structure changed significantly. From 1991 to 2012, the contribution of GDP by the service sector went up from 45.21% to 56.86% and the share of agriculture sector reduced from 29.39% to 17.39%. The GDP share of industrial sector changed very little from 25.40% to 25.75%, with the contribution of manufacturing industries falling slightly from 15.21% to 13.53%. Most notably, India's trade openness ratio shot up from only 16.69% in 1991 to 55.36% in 2012 (World Bank, 2014). By 2013, India has become the tenth largest economy by nominal GDP and third largest economy by purchasing power parity GDP. According to the data in 2013, India is also the 19th-largest exporter and the 10th-largest importer in the world, and expected to be the world's second largest economy by purchasing power parity GDP just after China by 2050 (PwC, 2013).

2.2.1.4 South Africa

When it gradually implemented the apartheid policy in the 1950s, the South African government met with protests internationally. In 1962, the United Nations General Assembly passed Resolution 1761, which was a non-binding resolution establishing the United Nations Special Committee against Apartheid, and calling for imposing economic and other sanctions on South Africa. Since then, economic sanctions against South Africa had been advocated around the world, particularly in the UK and US (Knight, 1990 and Lisson, 2000). However, because no economic sanctions or disinvestment were put into action immediately, the South African economy still achieved stable growth in the 1960s and 1970s. From 1961 to 1979, GDP grew at an annualised rate of 3.49%, and per capita GDP at 1.68%. The economic structure stayed relatively stable with the service sector contributing about 52% of GDP, the industrial sector rising gradually from 37.82% to 45.63% and peaking at 48.38% in 1980, in which the manufacturing share was around 22%, and the agriculture sector share falling from 11.21% to 5.97%. Similarly, South Africa's trade was not much affected either. In fact, its exports went up significantly from US$33.4 billion (1960) to US$89.6 billion (1979), and the exports to GDP ratio increased from 30.64% (1960) to 35.21% (1979) (in constant 2000 dollar) (World Bank, 2014).

However, after the international sanctions and disinvestments were implemented on a large scale in the mid-1980s, South Africa experienced considerable capital flight. Billions of capital moved out of the country each year, causing extensive damage to the economy. From the mid-1980s to mid-1990s, South Africa's GDP growth stagnated at an average annual rate of only 1.44%, and per capita GDP declined at an average annual rate of 1.66%. The trade openness ratio dropped precipitously from a high level of 62.73% in 1980 to a record low of 38.65% in 1992 (World Bank, 2014).

In 1994, Nelson Mandela was elected as president and apartheid was eventually ended. Then, international sanctions were lifted, international investment started increasing, and the economy went on to a steady growth path. From 1994 to 2012, South Africa's GDP grew at a stable average rate of 3.26% per year, and per capita income achieved an average annual growth rate of 1.6%. These growth rates were lower than the world averages and less than impressive compared to those seen in other emerging economies over the same period. Nevertheless, the country is widely deemed an emerging market with good economic growth prospects. In the post-apartheid economy, the output of the service sector increased from 60.42% of GDP in 1994 to 69.02% in 2012, accompanied by significant reductions in the GDP shares of agriculture sector (from 4.60% to 2.57%) and industrial sector (from 34.98% to 28.41%). The share of manufacturing fell from 20.92% to 12.38%. The trade openness ratio rose from 41.96% to 59.56% of GDP from 1994 to 2012, revealing its increasing participation in the global economy. By 2013, South Africa has become the second largest economy in Africa, accounting for about a quarter of Africa's GDP, and has a long term potential growth rate of 3.5% (PwC, 2013).

2.2.2 Environmental issues

Rapid economic growth reduces poverty on one hand, but it may lead to serious environmental degradation and natural resource depletion on the other hand. In Brazil, China, India and South Africa, decades of industrialisation and urbanisation have taken their toll on the environment. The specific environmental issues facing each country vary, however. Brazil is home to about one-third of the world's remaining rainforests, including about 60% of the Amazon rainforest. Deforestation has long been a major environmental concern for Brazil. Since 1970, over 600,000 squares kilometers of Amazon rainforest have been destroyed. The situation is expected to be worsened by increasing world demand for wood and soybean (Malhi et al., 2009). After decades of fast economic growth, China is facing mounting environmental problems. China's environmental problems are heavily driven by its industrialization process. Due to industrialization, thousands of factories have been built across the country emitting toxic waste gas and discharging contaminating effluent. As a result, massive area of China is covered by thick grey cloud, heavy smog fills cities, and almost all rivers and lakes are becoming dirty. It is estimated that thousands of premature deaths in China are closely related to air and water pollution (Zhang, 2014). India’s natural environment faces heavy burden from its large population, especially the non-environmental-friendly demand of energy and consumption waste. The rampant burning of fuelwood and biomass such as dried waste from livestock as the primary source of energy emits large amount of particulates and carbon dioxide, and may also affect human health. Due to the lack of sewage treatment operations, lots of consumption wastes have to be discharged into rivers, thus heavily polluting India’s water resource (Chandrappa and Ravi, 2009). The key environmental problem in South Africa is the lack of water resource. Millions of South Africans are living without safe water supply, about two thirds municipalities cannot say if they meet the drinking water standards or not, water supply to over one third residents is interrupted at least one day (WWF Global, 2009).

Despite Brazil, China, India and South Africa, each has their own specific environmental issues, a comparative study of these four countries calls for a unified environmental indicator, for it is not meaningful to compare countries with different environmental measures. However, since there is no universal consensus on one environmental measurement that can perfectly measure all environmental degradation and natural resource depletion, various environmental indices and indicators are used in empirical studies, such as CO_2 emissions, SO_2 emissions, dust, fine particles, greenhouse gas emissions (GHG), respirable suspended particle (RSP), smoke, arsenic, cadmium, mercury, lead, nickel, pathogens, access to safe water, biodiversity loss, deforestation, energy consumption, environmental R&D, hazardous waste, solid wastes, traffic volume, and urban sanitation among others (Grossman and Krueger, 1991, 1993, 1995, Shafik and Bandyopadhyay, 1992, Panayotou, 1993, Selden and Song, 1994, Shafik, 1994, Carson, et al., 1997, Cole et al., 1997, Hettige et al., 1997, Lim, 1997, Hilton and Levinson, 1998, Kaufmann et al., 1998, Koop, 1998, Mather and Needle, 1999, Koop and Tole, 1999, Barrett and Graddy, 2000, Cavlovic et al., 2000, and Hettige et al., 2000, Pal et al., 2000, Perrings and Ansuategi, 2000, Minliang et al., 2001, Roca and Alcantara, 2001, Stern and Common, 2001, Ansuategi and Escapa, 2002, Dietz and Adger, 2003, Friedl and Getzner, 2003, Martinez-Zarzoso, Bengochea-Morancho, 2004, Jayanthakumaran and Liu, 2012, Zhang, 2014).

Among all environmental indicators, CO_2 emissions and SO_2 emissions are of particular interest for reasons as follows. Firstly, CO_2 emissions and SO_2 emissions are important environmental indicators for global and local environment. As a typical global pollutant, carbon dioxide (CO_2) does not have direct detrimental effect on human health, but it is an important greenhouse gas (GHG) causing global warming. It is estimated that CO_2 emissions directly contribute to the greenhouse effect up to 26% (Kiehl and Trenberth, 1997). Moreover, CO_2 is also a major source of ocean acidification since it dissolves in water to form carbonic acid. In contrast, sulfur dioxide (SO_2) is a typical local pollutant that has significant impact on human health. Scientific evidence shows that short-term exposure to SO_2 emissions may cause an array of adverse respiratory effects, such as wheezing, chest tightness and shortness of breath; while long-term exposure to SO_2 emissions may be linked with respiratory illness, alterations in the lungs' defenses and aggravation of existing cardiovascular disease (Pope et al., 2007). Moreover, SO_2 is also the major precursor of acid rain, which has adverse impact on forests, freshwaters, soils, killing insect and aquatic life-forms as well as leading damage to buildings and human health (Likens and Bormann, 1974).

Secondly, because CO_2 emissions and SO_2 emissions are important indicators for global and local pollution, they are commonly used environmental indicators in many existing empirical studies. Since Grossman and Krueger (1991) and Shafik and Bandyopadhyay (1992), there have been hundreds of empirical studies on the CO_2 emissions and SO_2 emissions (detail review can be found in Panayotou, 1994, Borghesi, 1999, Levinson, 2000, Lieb, 2003, Stern, 2004, Cole and Neumayer, 2005, He, 2007).

Last but not least, Brazil, China, India and South Africa are all world top CO_2 and SO_2 emitting countries, and it is widely believed that CO_2 and SO_2 emissions in these four countries are influenced by their patterns of economic growth and international trade. Therefore CO_2 and SO_2 emissions can be used as environmental indicators for comparative empirical study between these four countries, and also studying CO_2 and SO_2 emissions in these four countries can contribute to world CO_2 and SO_2 emissions issues. Excessive carbon dioxide (CO_2) emissions are common environmental issues for Brazil, China, India and South Africa. As shown in table 2.1, Brazil, China, India and South Africa are world top 20 CO_2 emitting countries by aggregate emissions, respectively emitting roughly 393, 7032, 3443, 436 million tons of CO_2 emissions every year, accounting 1.32%, 23.50%, 5.83% and 1.46% of world total CO_2 emissions and ranking 17th, 1st, 3rd and 13th in world. Not only the CO_2 emissions, but also the SO_2 emissions. Table 2.2 shows that all four countries: Brazil, China, India and South Africa are top SO2 emissions countries in the world. Particularly, China is the largest contributor for world sulfur dioxide, with India of the third. Brazil, China, India and South Africa emit 1468, 32673, 6275 and 2477 million tons of SO_2 emissions, accounting respectively 1.24%, 28.29%, 5.43% and 2.14% world total SO_2 emissions and ranking respectively 13^{th}, 1^{st}, 3^{rd} and 7^{th} in the world.

Table 2.1: CO_2 emissions in 2008

Country	Total CO_2	% of world	World ranking
Brazil	393,220	1.32	17
China	7,031,916	23.50	1
India	3,442,698	5.83	3
South Africa	435,878	1.46	13
Total	**11,303,712**	**32.11**	

Total CO_2: country aggregate CO_2 emissions in thousands of metric ton.
Source: World Development Indicator 2014

Table 2.2: SO_2 emissions in 2005

Country	Total SO_2	% of world	World ranking
Brazil	1,438	1.24	13
China	32,673	28.29	1
India	6,275	5.43	3
South Africa	2,477	2.14	7
Total	**42,863**	**37.10**	

Total SO_2: country aggregate SO_2 emissions in thousands of metric ton.
Source: Smith et al., (2011)

2.2.3 Growth, trade and pollution in the four developing countries: 1960-2012

Over the past half century, one fascinating phenomenon in modern economic history is the astonishing economic growth in emerging economies, such as Brazil, China, India and South Africa. As shown in figure 2.1, the years between 1960 and 2012 saw exponential growth in China in both total GDP and per capita GDP; steady growth in India and significant increases in per capita GDP in Brazil and South Africa. By 2014, these four countries have become respectively the world's 7th, 2nd, 10th and 28th largest economy by nominal GDP (World Bank, 2014).

The fast economic growth in these four countries is widely believed to be driven by their rapid internationalization. Figure 2.1 shows that generally speaking, trade openness ratios in China and India have been increasing along with their rapid economic growth, whereas in Brazil and South Africa values of the ratio have fluctuated around a stable long-run trend. In 2012 (WB, 2014), total volume of trade reached 6259, 2569 and 337 billion constant 2000 US dollars, accounting for 26.54%, 51.84%, 55.36% and 59.56% of total GDP respectively in Brazil, China, India and South Africa.

Although none of the four countries is new to the environmental degradation, there is no doubt that rapid economic growth and integration into the world economy have aggravated some of the existing problems and brought about some new ones. As shown in figures 2.2 and 2.3, CO_2 and SO_2 emissions in all four countries have soared up unprecedentedly since the 1960s, when their economies started growing rapidly. In 2008, In 2008, Brazil, China, India and South Africa emitted respectively 0.39, 7.03, 1.74 and 0.44 billion metric tons of carbon dioxide (CO_2), which made them the 17th, 1st, 3rd and 13th largest CO_2 emissions country in the world, contributing 1.32%, 23.5%, 5.83% and 1.46% of the world's total CO_2 emissions (table 2.1). In 2005, Brazil, China, India and South Africa released respectively 1.44, 32.67, 6.27 and 2.48 million metric tons of sulfur dioxide (SO_2), contributing 1.24%, 28.29%, 5.43% and 2.14% of the world's total SO_2 emissions (table 2.2)

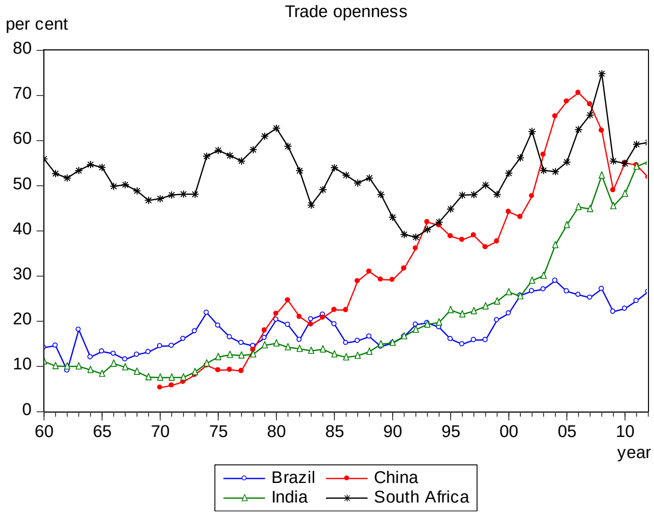


Figure 2.1: Trade openness ratio in the BASIC
Source: World Bank, World Development Indicator 2014

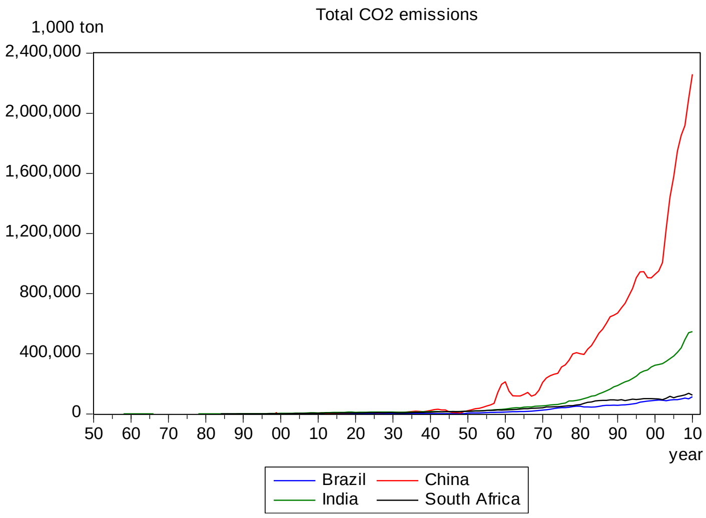


Figure 2.2: CO_2 emissions at national level
Source: World Bank, World Development Indicator 2014

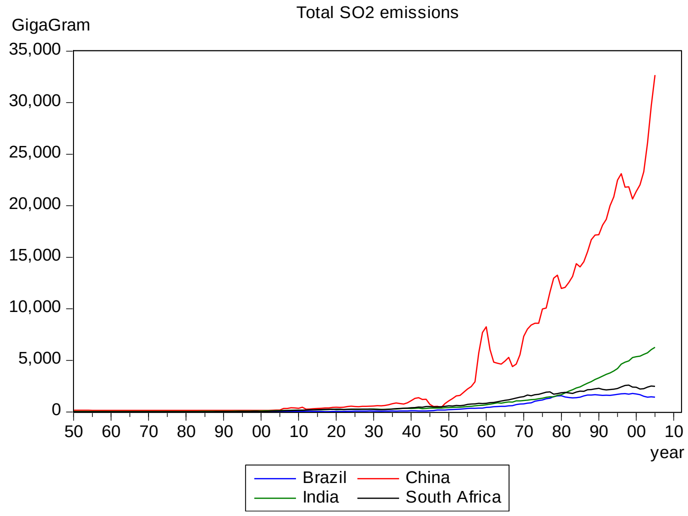


Figure 2.3: SO_2 emissions at national level
Source: Smith et al., (2011) [GigaGram = 1,000 tons]

2.3. Literature Review

In this section, we first briefly introduce three hypotheses: the Environmental Kuznets Curve (EKC hereafter) hypothesis, Pollution Haven Hypothesis (PHH hereafter) and Factor Endowment Hypothesis (FEH hereafter) (detail review see chapter 1). Then we review exiting empirical studies of the EKC, in particular the estimating methods. Lastly, we review empirical studies of the causal relationship between economic growth, international trade and environmental degradation.

2.3.1 Three hypotheses: EKC hypothesis, PHH and FEH

The impact of economic growth and globalization on the natural environment has long been debated. On one hand, optimists support the "pollute first and then clean up" argument (Beckerman, 1992; Barlett, 1994; and Lomborg, 2001). By extension, globalization must be good for the environment since it can stimulate economic growth and in turn speed up the "pollute first and then clean up" process. On the other hand, pessimists argue that developed countries only managed to clean up in their later stages of development by shifting pollution-intensive industries to developing countries. Developed countries' experience of "pollute first and then clean up" is, therefore, unlikely to be replicated in developing countries (Ekins, 1997; Suri and Chapman, 1998). The optimistic view emanates from the EKC hypothesis, while the pessimistic view is informed by the PHH.

Theoretically, economic growth can affect the interaction between human activities and the natural environment through three channels: scale effect, technique effect, and composition effect (Grossman and Krueger, 1995; de Bruyn, 1997; Antweiler et al., 2001; Stern, 2002; and Copeland and Taylor, 2004). The scale effect refers to the environmental impact of a simple scale-up of the economy, which monotonically increases environmental degradation ceteris paribus. The technique effect refers to the environmental impact of technology upgrades, that reduce the pollution intensity of production processes. Such upgrades abate environmental degradation ceteris paribus. The composition effect concerns changes in the share of pollution-intensive production in total output. Holding the state of technology and scale of economy constant, there will be less pollution if a smaller share of the economy's resources is devoted to producing pollution-intensive goods.

Analogically, the environmental impact of globalization in general and international trade in particular also operates through the three channels. Theoretical as well as empirical studies abound on the growth-enhancing effects of international trade. This will strengthen the scale effect of growth on the environment (Sachs and Warner, 1995; Frankel and Romer, 1999; Deme, 2002; Wacziarg and Welch, 2008). Research has also shown that trade can promote the adoption of new technology. Thus, the technique effect may also be enhanced by trade via importing capital goods embodying green technology, exposure to environmentally friendly practices and institutions, and spillovers of the new technology and practices in the economy (Antweiler et al., 2001, de Bruyn and Heintz, 2002, and Copeland and Taylor, 2004).

The scale and technique effects of trade are unambiguous at least in theory. The trade-induced composition effect, however, is uncertain a priori because it may be subject to two opposing mechanisms of comparative advantage, if we consider comparative advantage to be a function of a country's environmental regulation and endowment of capital. The first mechanism is captured by the PHH which asserts the specialisation of dirty or clean industries depends on the relative stringency of environmental regulations between countries. Because developing countries usually have relatively less stringent environmental regulations, they have comparative advantage in producing pollution intensive goods. By specialising in dirty production processes, developing countries become "pollution havens". It follows that the inverted U-shaped relationship between development and pollution as depicted by the EKC hypothesis may not be observed in all developing countries as eventually there be nowhere to transfer pollution (Suri and Chapman, 1998, de Bruyn and Heintz, 2002).[13]

The second mechanism that may influence the trade-induced composition effect is a straightforward application of the Heckscher-Ohlin theorem and can therefore be

[13] This argument is based upon the assumption that the consumption habit does not change in developed countries, holding scale and technique effects constant or changes in scale and technique effects offset each other.

called the factor endowment hypothesis (FEH). The FEH starts with the standard Hechscher-Ohlin prediction that the relative supply of production factors determines the pattern of specialisation across countries, i.e., capital-abundant countries will export capital-intensive goods while labour-abundant countries will export labour-intensive goods. On the assumption that capital-intensive goods tend to be more polluting[14], the FEH states that the capital-abundant developed countries are more likely to specialise in producing and exporting pollution-intensive goods while importing labour-intensive goods from developing countries. Tough the two mechanisms – PHH and FEH – work in opposite directions, they are not mutually exclusive. Depending on which of the two mechanisms dominates in a particular economy, trade may induce either a compositional shift away or towards pollution-intensive industries.

2.3.2 The EKC: Empirical Studies

There are an enormous amount of empirical EKC studies in the literature. These studies usually estimate a reduced form EKC equation where a measure of pollution is specified as a cubic or quadratic function of some measure of per capita income. The cubic functional form allows for N- or inverted N-shaped EKC as suggested by some theoretical studies (Andreoni and Levinson, 2001, Jones and Manuelli, 2001 among others), implying environmental degradation may eventually tend to plus (or minus) infinity. The quadratic functional form only allows for U- or inverted U-shaped EKC as proposed in most theoretical studies (Lopez, 1994, Seldon and Song, 1995, and Di Vita, 2004 among others). The environmental and income indicators may enter the equation either in levels or in natural logarithms. The choice between using levels or logarithms of the variables in regression is not as inconsequential as it may seem. For example, a quadratic function in levels would give rise to a symmetric bell-shaped EKC with the implication that pollution could be eliminated at the same speed as it was generated. By contrast, a quadratic function in logarithms would result in a positively skewed inverted U-shaped curve, implying that pollution would be abated at a lower speed than it was generated (Jayanthakumaran and Liu, 2012). Given that in reality pollution is often cleaned up gradually via assimilation by the ecosystem and abatement effort, the natural logarithm function seems more appropriate.

Due to the absence of a consensus pollution measure, various environmental indicators have been examined for testing the EKC hypothesis. These indicators may be grouped into three main categories: air pollution indicators, water pollution indicators

[14] According to Antweiler et al. (2001) and Copeland and Taylor (2004), capital intensive production process is believed to be relatively dirty production process.

and other indicators. Air pollution indicators measure air quality or the amount of pollutants released into the atmosphere, such as carbon monoxide (CO), dust, fine particles, respirable suspended particle (RSP), smoke, sulphur dioxide (SO_2), and suspended particulate matters (SPM) among others (Grossman and Krueger, 1991, 1993, 1995, Panayotou, 1993, Selden and Song, 1994, Shafik, 1994, Cole et al., 1997, Kaufmann et al., 1998, Koop, 1998, Pal et al., 2000, Roca and Alcantara, 2001, Stern and Common, 2001, Ansuategi and Escapa, 2002, Friedl and Getzner, 2003, Martinez-Zarzoso and Bengochea-Morancho, 2004 among others). Water indicators are often connected with toxic pollutants in the water, such as arsenic, cadmium, mercury, lead, nickel, and pathogens among others (Grossman and Krueger, 1995, Hettige et al., 1997, Hilton and Levinson, 1998, Barrett and Graddy, 2000, Cavlovic et al., 2000, and Hettige et al., 2000 among others). Apart from these two main groups of indicators, empirical EKC studies have examined many other indicators in wider context, such as access to safe water, biodiversity loss, deforestation, energy consumption, environmental R&D, hazardous waste, solid wastes, traffic volume, and urban sanitation among others (Shafik and Bandyopadhyay, 1992, Panayotou, 1993, Carson, et al., 1997, Lim, 1997, Mather and Needle, 1999, Koop and Tole, 1999, Cavlovic et al., 2000, Perrings and Ansuategi, 2000, Minliang et al., 2001, Dietz and Adger, 2003 among others). Contrary to the wide variety of environmental indicators, income is almost exclusively represented by GDP per capita.

Early empirical EKC studies are surveyed and summarized in Grossman and Krueger (1991), Shafik and Bandyopadhyay (1992) and Panayotou (1993). After studying several pollutants, such as SO_2, NOx, and SPM, these authors find a bell-shaped curve with the turning point occurring at income levels ranging from \$3000 to \$5000[15]. Later studies in the mid-1990s (e.g. Selden and Song, 1994; and Grossman and Krueger, 1995) seem to support these findings, but Selden and Song (1994) find much higher income levels for the turning points of the SO_2, NOx, SPM and CO curves. In a study using global data, Shafik (1994) finds that the inverted U shape does not hold for some environmental indicators, such as water, urban sanitation, municipal waste, CO_2 and fecal coliform. For these indicators, a linear or cubic function provides a better fit.

Motivated by the early seminal works, a large amount of empirical studies were published between the mid-1990s and early 2000s, Borghesi (1999), Lieb (2003), Panayotou (2003) all provide a very detailed review of these publications. Compared to

[15] These values are expressed in constant 1985 US dollars. Shafik and Bandyopadhyay (1992) adjusted GDP values for Purchasing Power Parity (PPP), so their turning point is in PPP adjusted 1985 US dollars.

earlier studies, findings from the studies conducted during this period are far more ambiguous. Various shapes of the EKC are identified, such as linear, U-shaped, inverted U-shaped, N-shaped and even inverted N-shaped. The income level at the turning point varies from less than $2000 to as high as more than a million dollars.[16] A study worthy of special note is Cole et al (1997) who study a variety of pollutants including CO_2, SO_2, SPM and municipal waste, as well as such indicators as energy use and traffic volumes which correlate with but do not directly measure pollution. They find that the inverted U shape EKC only exists for local air pollutants whilst indicators of more global or indirect effect seem to monotonically increase as income rises. This finding raises the question of why there is no unequivocal support of the EKC for any environmental indicators. To seek an answer, Ekins (1997) examines the robustness of EKC estimations, and shows previous empirical EKC studies may not be robust. Ekins (1997) argues any improvements in environmental quality as income rises are likely to be a result of the enactment of environmental policy rather than endogenous changes in economic structure or technology and suggest further studies need take into account of policy and institutional factors.

One early paper that considers policy and institutional factors is Panayotou (1997), who explicitly incorporates policy into the conventional EKC equation. Panayotou (1997) finds policies and institutions can significantly reduce environmental degradation at even a low income level and also speed up the improvement at higher income levels. Another interesting paper that incorporates policy and institutional indicators as well as education factors is Torras and Boyce (1998). Using the same data set as Grossman and Krueger (1995), Torras and Boyce (1998) examine the relationship between seven air and water pollutants and per capita income as well education and institutional indicators. They find that literacy, political rights and civil liberties all have strong effects on environmental quality in low-income countries. Since then various factors have been introduced into the EKC equation, including energy price, liberty, income inequality, energy input, electricity tariff, debt per capita, and political right (De Bruyn et al., 1998, Barrett and Graddy, 2000, Heerink et al., 2001, Roca et al., 2001, and Halos, 2003 among others)

Among all additional variables introduced, international trade, as represented by trade openness, trade policy, dirty exports and imports, is often considered as an important factor to the income-environment relationship. In one of the first EKC papers, Grossman and Krueger (1991) use trade openness (ratio of exports plus imports to

[16] For instance, Cole et al. (1997) find the turning point for transport energy use is $4 million.

GDP) to estimate the effect of international trade on sulfur dioxide concentration, dark mater (smoke) concentration and suspended particles concentration. They find trade openness is positively related to environmental quality. Gale and Mendez (1998) employ a trade policy measure and find that trade policy has no statistically significant effect on pollution. Cole (2004) incorporates a measure of trade in dirty products between developed and developing countries into EKC estimation. Using a sample of OECD countries, Cole cannot exclude the possibility that the displacement and migration of dirty industries do not contribute to the formation of inverted U shape EKC. Kearsley and Riddel (2010) extend Cole's (2004) study with disaggregated manufacturing imports and exports shares, and find little evidence that trade plays a significant role in shaping the EKC in OECD countries.

There are also some studies that attempt to decompose the EKC relationship into scale, composition and technique effects. Grossman and Krueger (1991) are among the first to explain the inverted U shape relationship between pollution and income as resulting from the interaction between the expansion of economic activity (scale effect), expansion or contraction of pollution-intensive activities (composition effect) and adoption of cleaner technologies (technique effect). Panayotou (1997) uses GDP per unit of area, industrial share in GDP and income to capture the scale, composition and technique effect. He studies the ambient SO_2 concentrations and finds that the scale effect is strong but its effect is decreasing over time. The composition effect shows an expected J shape. After controlling for scale and composition effects, a rise in per capita income reduces ambient SO_2 concentrations, indicating that the technique effect is positive for the environment.

De Bruyn et al. (1998) decompose pollution emissions into level of emissions intensity and level of GDP. They find the positive effect of economic growth on emissions is largely compensated by the technological and structural changes in developed countries. Stern (2002) decomposes changes in emissions per capita into five components: scale, emissions specific technical progress, overall technical progress, output mix and input mix. Using a panel consisting of 64 developed and developing countries, Stern finds that both emissions specific and overall technical progress technique effects are main factors offsetting the scale effect. Input and output mixes may have effect in some countries, but generally their role in changing global emissions is small. Interestingly, an expansion of the service sector may lead to more SO_2 emissions due to the rise in consumption. Borghesi et al (2010) decompose greenhouse gas (GHG) emissions into five social-economic determinants: population, per capita income, energy intensity, share of fossil fuels on energy consumption and the intensity of GHG emission per unit of fossil fuel consumed. They find that the growth rate of CO_2 emissions slowed down between 1971 and 2000, and will be reduced further from 2007 to 2030, thanks chiefly to technological progress which reduces global energy demand and intensity.

2.3.3 The EKC: Estimation Methods

Early empirical studies of the EKC invariably employ cross country data to estimate a single EKC equation (Grossman and Krueger, 1991, 1993 and 1995; Shafik and Bandyopadhyay, 1992; Panayotou, 1993; Selden and Song, 1994; and Shafik, 1994 among others). This constrains the EKC relationship in different countries to have the same functional form, parameter estimates and income turning point. This strong homogeneity assumption has been criticized by later studies (Perman and Stern, 1999 and 2003, Martinez-Zarzoso and Bengochea-Morancho, 2003 and 2004, Brock and Taylor, 2004, Dijkgraaf and Vollebergh, 2005, and Dijkgraaf et al., 2005 among others). Brock and Taylor (2004) cast doubt on this homogeneity assumption on both theoretical and empirical grounds. They argue that income-emissions profiles are likely to vary across countries if countries differ in initial conditions or in structural parameters such as savings, technological change (in abatement) and population growth rates. Such divergences across countries (over time) would not be adequately captured by country- and time-specific fixed effects in an econometric modelling environment based on the homogeneity assumption. Therefore, Brock and Taylor (2004) claim that it is hardly surprising that the EKC literature has so many difficulties in demonstrating this relationship. Using a dataset of 24 OECD countries for the period of 1960 – 1997, Dijkgraaf and Vollebergh (2005) support Brock and Taylor's (2004) argument. They find that the assumption of homogeneous EKC across OECD countries is not innocent, due that the estimations of the EKC are sensitive to the homogeneity assumption and allowing heterogeneity across countries give very different EKC estimation results. Thus Dijkgraaf and Vollebergh (2005) suggest more work should be carried out for individual countries.

De Bruyn et al. (1998) also argue panel estimation based on cross-country data, even when allowing for fixed country effects, is inadequate, since the relationship between income and pollution may be country-specific and each country may well has it unique EKC. De Bruyn et al. (1998) thus carry out Ordinary Least Squares (OLS) estimations for each country in their sample, including Netherlands, UK, USA and West Germany. De Bruyn et al.'s (1998) view that EKC studies should allow for inter-country heterogeneity is shared by a number of more recent studies, including Dasgupta et al. (2002), De Bruyn (2002), Roca et al (2001), Friedl and Getzner (2003), Egli (2004), Deacon and Norman (2006), Halicioglu (2009), Iwata et al (2010), Jalil and Feridun (2011), Piaggio and Padilla (2012).

Since empirical EKC studies on individual countries employ time series variables, the unit root and cointegration problems should be concerned. Stern and Common (2001) argue that because a single global cointegrating vector is very unlikely for the EKC, a simple first difference may be sufficient to remove potential stochastic trend[17]. Thus they estimate the EKC in first differenced form and find that SO_2 emissions monotonically increase as income rises in both OECD and non-OECD countries. Perman and Stern (2003) study a panel of 74 countries for the period 1960-1990, and find SO_2 emissions are integrated series and cointegrated with GDP, indicating a static EKC regression model may produce spurious results. Thus they employ dynamic error correction approaches, such as mean group (MG) estimator and pooled mean group estimator (PMG). Perman and Stern (2003) find that the choice of estimated model has a huge impact on the shape of EKC. For instance, the turning point estimates from the unrestricted model, pooled mean group restricted model, and static fixed effects model are US$10,795, US$15,063 and US$82,746, respectively. Thus Perman and Stern (2003) conclude that the EKC is a problematic concept. Motivated by Perman and Stern (2003), empirical EKC studies for individual countries test the existence of a unit root for various environmental indicators, such as SO_2, NO_x, CO_2, CO, NH_3, CH_4, PM and non-methane volatile organic compounds (NMVOC) (Friedl and Getzner, 2003, Egli, 2004, Deacon and Norman, 2006, Halicioglu, 2008, and Piaggio and Padilla, 2012 among others). These empirical studies achieve a consensus finding that environmental variables have a unit root.

Since the EKC may imply a long-run relationship between income and pollution, existing empirical EKC studies employ cointegration tests, but provide ambiguous evidence on the EKC cointegrating relationship (see for example, Perman and Stern, 2003, Iwata et al., 2010, Menyah and Wolde-Rufael, 2010, Jalil and Feridum, 2011, and Piaggio and Padilla, 2012). For instance, instead of an inverted U shape, a large proportion of sample countries in Perman and Stern (2003) are showing a U shape or monotonic cointegrating relationship.

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[17] Stern and Common (2001) do not carry out unit root tests by themselves, they argument that environmental indicators are I(1) series bases on the findings of Perman and Stern (1999), which suggests that income and environmental variables are I(1) series in the EKC regression.

2.3.4 Empirical studies on the causal relationship between growth, trade and the environment

The relationship among income, trade and environmental degradation is complex and subject to the influence of a host of forces, some of which work in opposite directions. Take, for example, income and environmental degradation. The EKC hypothesis suggests that income growth causes changes in environmental degradation, but the relation is nonlinear – pollution increases with income in the early stage of development and decreases after income reaches a certain threshold. To complicate matters further, there is also the possibility of an "environmental feedback effect", or the negative impact on economic activity inflicted by certain types of environmental damage (Stern et al., 1996 and Pearson, 1994 among others). As for the relationship between international trade and environmental degradation, the PHH predicts that trade aggravates environmental degradation in developing countries but mitigates it in developed countries. The FEH implies, however, that effects exactly opposite to the PHH predictions may also be at work. Even the relationship between economic growth and international trade is not free of controversies. The Trade-led Growth Hypothesis (TGH) suggests that international trade causes economic growth, while the Growth-led Exports Hypothesis (GEH) implies economic growth causes international trade[18].

Since the direction of causality and sign of impact of the relationship between income, trade and environmental degradation is theoretically ambiguous, it becomes an empirical issue. Summarised in tables 1–3 in appendix 2.1 are the main characteristics and conclusions of selected previous studies on the causality between income and trade, income and environmental degradation, and trade and environmental degradation.

One important finding emerging from this body of literature is that the properties of the stochastic processes followed by the variables in question affect the causality test results. The presence of unit root and cointegration poses a particular challenge and must be sufficiently accounted for in model specifications.

Most previous studies on the causal relationship between income, trade and environmental degradation focus on developed countries. Only a few studies include developing countries in their samples. To our knowledge, Brazil, China, India and South Africa are covered in only four studies on the causality between economic growth and international trade: Jung and Marshall (1985), Dutt and Ghosh (1996), Liu et al.

[18] Interestingly, we can find literature for Growth-led Exports, but hardly any for Growth-led Imports. However, if a country's economy grows rapidly, it is also likely to increase its imports, such as oil, intermediate goods, etc., as evidenced by China's experience (Arora and Vamvakidis, 2010).

(1997), Shan and Sun (1998), and Liu et al. (2002). Similarly, among causality test studies on the relationship between economic growth and environmental degradation, the four countries are found only in Zhang and Cheng (2009), Chang (2010), Peng and Sun (2010), Tiwari (2011), and Pao and Tsai (2011). For the relationship between international trade and environmental degradation, we cannot find any causality test studies covering the four countries.

2.4. Methodology and Data

This section introduces our methodology and describes our data set. We start with unit root and cointegration tests, and then move on to discuss causality tests. In section 2.4.3, we discuss the specification of the equation for the EKC. In section 2.4.4 we show how the EKC equation can be augmented to test the effects of international trade on pollution and the shape of EKC. The data used in our empirical analysis in this chapter are described in section 2.4.5.

2.4.1 Unit root and cointegration tests

The stochastic behaviour of time series variables has attracted much attention since the seminal work of Nelson and Plosser (1982), who finds that most macroeconomic time series have a unit root and are nonstationary. An Ordinary Least Squares (OLS) regression run on nonstationary series is liable to the spurious regression problem. A spurious regression refers to a regression that shows significant results due to the presence of a unit root in variables included in a regression, when variables included in a regression are actually uncorrelated I(1) processes. Regression result of a spurious regression often shows highly statistically significant coefficients, and high degree of fit, but extremely low value for Durbin-Watson statistic[19]. These regressions results often mislead researchers to conclude that there is a significant statistical relationship, but in fact there should be none (Yule, 1962, Granger and Newbold, 1974).

Since our income, trade and environmental indicators are time series variables, it is important to examine their stationarity. If a variable is stationary, then it is mean-reverting and any shocks will have a transitory impact only. If a variable has a unit root, then it is non-stationary, it is non-mean-reverting and any shocks will have permanent impact in the long run. Unless regressed nonstatoinary series are cointegrated, a regression of nonstationary series may be subject to the spurious regression problem providing misleading results (Granger and Newbold, 1974). To examine the presence of

[19] The degree of fit as measured by the and adjusted may not be very high, but usually apparently higher than the Durbin-Watson value in spurious regressions (Granger and Newbold, 1974).

unit roots in our data series, we utilise ADF test and other four unit root test with structural breaks as follows.

Conventionally, unit root property of series is often tested by the Augmented Dickey-Fuller (ADF hereafter) test introduced by Dickey and Fuller (1979). The ADF test examines unit root by three separate models testing three stochastic processes: random walk, random walk with a drift, and random walk with a drift and deterministic trend respectively. Nelson and Plosser (1982) apply the ADF test to US historical time series, and find most macroeconomics variables have a unit root. However, Nelson and Plosser's (1982) finding is severely challenged by Perron (1989), who argues that the standard ADF test is biased towards the non-rejection of the null hypothesis in the presence of a structural break in time series data. So Perron (1989) develops a modified ADF test using dummy variables to account for one exogenous structural break. After applying this modified ADF test to Nelson and Plosser's (1982) US dataset, Perron (1989) finds most macroeconomic variables are stationary with deterministic trends: variables are mean reverting after small and frequent shocks, and persistence of variables only arises due to large and infrequent shocks.

Although Perron (1989) introduces an interesting perspective on conventional unit root tests, Perron's (1989) approach is not free of criticism, especially on the exogeneity assumption of the structural break, and the number of structural break. These criticisms include Zivot and Andrews (1992), and Lumsdaine and Papell (1997)[20]. To modify Perron (1989) by an endogenous approach, Zivot and Andrews (1992) develop a sequential unit root test allowing the tested series to choose one break point that is least favourable for the null hypothesis of having a unit root. Zivot and Andrews (1992) apply their approach to Nelson and Plosser's (1982), but find contrary results to Perron's (1989) conclusion that most macroeconomics variables are stationary with one exogenous break. Instead, Zivot and Andrews' (1992) results mostly cannot reject the null hypothesis of having a unit root, against the alternative of being trend stationary with one endogenous break, which supports Nelson and Plosser's (1982) finding that most macroeconomics variables have a unit root. Lumsdaine and Papell (1997) point out that neither Perron (1989) test nor Zivot and Andrews (1992) test is adequate in the presence of more than one break, so they extend Zivot and Andrews (1992) test by allowing two endogenous breaks. The results of Lumsdaine and Papell's (1997) test for

[20] Detail discussions are in Banerjee et al (1992), Christiano (1992), Perron and Vogelsang (1992), Zivot and Andrews (1992), Lumsdaine and Papell (1997), Perron (1997 and 2005), Byrne and Perman (2007), and Glynn et al. (2007) among others.

Nelson and Plosser's (1982) dataset show more evidence against the null hypothesis of having a unit root, supporting Perron's (1989) finding of no unit root but less strong.

Zivot and Andrews (1992), and Lumsdaine and Papell (1997) extend conventional ADF test to allow for up to two endogenous structural breaks. However, one obvious criticism is that neither of these tests considers the unit root process with structural break. This potential bias could lead to serious size distortions (Nunes et al, 1997), loss of testing power (Perron, 2005, and Glynn et al, 2007), and misleading series property (Lee and Strazicich, 2003). Lee and Strazicich (2003) point out that the rejection of the null hypotheses in Zivot and Andrews (1992), and Lumsdaine and Papell (1997) tests does not imply the rejection of a unit root process with structural break, so it may be erroneous to interpret a rejection of the unit-root null hypothesis from both tests as an indication that the tested time series is trend stationary with breaks. They complement Zivot and Andrews (1992), and Lumsdaine and Papell (1997) tests by developing a minimum Lagrange Multiplier (LM) test, which allows structural breaks in both null and alternative hypothesis.

This section briefly reviews ADF test, modified ADF tests with one exogenous break (Perron, 1989), one endogenous break (Zivot and Andrews, 1992), two endogenous breaks (Lumsdaine and Papell, 1997), and LM test with two endogenous breaks (Lee and Strazicich, 2003). Since there is no general consensus on the most appropriate testing approach (Glynn et al., 2007), a thorough investigation on the time series property of our dataset requires us employing all five unit root tests.

If some linear combination of two or more time series integrated of the same order has a lower order of integration, then these series are said to be cointegrated. Engle and Granger (1987) first introduce and test for cointegration among non-stationary time series by a two-step procedure. In the first step of the Engle-Granger procedure, the long-run cointegrating relation is estimated; in the second step, residuals from the first-step regression are used as an explanatory variable to estimate a short-run model with an error correction mechanism. This two-step procedure involves a pre-testing of the integration order of tested variables, potentially introducing uncertainty into the analysis of long-run relations (see, for example, Cavanagh et al. (1995)). Pesaran et al. (2001) develop a bounds testing procedure for testing the existence of a long-run relationship in Autoregressive Distributed Lag (ARDL) models. To test the existence of cointegration, we opt for both the Engle-Granger (1987) two-step procedure and Pesaran et al. (2001) procedure. Our unit root test results are reported in table 2.13 and cointegration test result is reported in table 2.14.

Despite the fact that Engle and Granger's (1987) error correction model (ECM) and the Autoregressive Distributed Lag (ARDL) model are often used to address the potential cointegration problem in the EKC estimation (important publications are Perman and Stern, 2003, Egli, 2004, Halicioglu, 2009, Iwata et al., 2010, Menyah and Wolde-Rufael, 2010, Jalil and Feridum, 2011, and Piaggio and Padilla, 2012), it is no harm to apply single equation cointegration estimation models, such as Fully Modified Ordinary Least Square (FMOLS), Canonical Cointegrating Regression (CCR) and Dynamic Ordinary Least Square (DOLS), because the relative small sample performance between these estimators and ARDL model is still inconclusive (Pesaran and Shin, 1999)[21]. In the present of a unit root and cointegration, conventional Ordinary Least Square (OLS) estimator is still consistent, but its limiting distribution is contaminated by second order bias terms (Phillips and Hansen, 1990). The Fully Modified Ordinary Least Square (FMOLS) model proposed by Phillips and Hansen (1990) modifies the OLS estimator to deal with the second order bias[22] by two modifications: first, replacing the dependent variable by a suitably constructed variable; and second, adding a correction factor. Park's (1992) further modified the FMOLS by stationary transforming both dependent and independent variables to remove the long run dependence between the cointegrating equation and stochastic regressors innovations, and this approach is named the Canonical Cointegrating Regression (CCR) model. The Dynamic Ordinary Least Square (DOLS) model incorporates leads and lags of first differenced independent variables in the cointegrating regression to mitigate second order bias by ensuring the error term is orthogonal to the entire history of the stochastic regressors innovations (Saikkonen, 1992 and Stock and Watson, 1993).

2.4.2 Granger causality test

The concept of causality commonly used in time series analysis is formalised by Granger (1969). The definition of Granger causality rests on two principles: (1) changes in the cause variable precede changes in the effect variable; (2) the cause variable contains unique information that helps forecast the effect variable. In a bivariate context, a vector autoregressive model (VAR) is often specified to test the null hypothesis of the absence of Granger causality as follows:

$$X_t = c_1 + \sum_{i=1}^{l} \alpha_i X_{t-i} + \sum_{i=1}^{l} \beta_i Y_{t-i} + u_t \qquad (2.1)$$

$$Y_t = c_2 + \sum_{i=1}^{l} \gamma_i X_{t-i} + \sum_{i=1}^{l} \delta_i Y_{t-i} + v_t \qquad (2.2)$$

[21] Pesaran and Shin (1999) find that the small sample performances between ARDL and FMOLS estimators are not clear cut, for they depend on data generating processes and the signal-to-noise ratio.

[22] This second order bias is caused by the long run correlation between the cointegrating equation and stochastic regressors innovations, detail discussion in (Phillips and Hansen, 1990).

where X and Y are two time series to be tested, t represents time, c_1 and c_2 are constant terms, α_i, β_i, γ_i and δ_i are regression coefficients, u and v are two disturbance terms that are assumed to be uncorrelated white-noise series, i.e. $E[u_t u_s] = E[v_t v_s] = 0$ when $t \neq s$, and $E[u_t v_s] = 0$ for all $t, s \in T$, T is the set of time periods.

The results from estimating the above bivariate VAR will reveal the following four cases: First, if at least one of the estimated coefficients of lagged Y in equation 2.1 is statistically different from zero as a group (i.e., the null hypothesis: $\beta_1 = \beta_2 = \cdots = \beta_l = 0$ can be rejected), while the estimated coefficients of lagged X in equation 2.2 are not statistically different from zero as a group (i.e., the null hypothesis: $\gamma_1 = \gamma_2 = \cdots = \gamma_l = 0$ cannot be rejected), then there is a unidirectional Granger causality from Y to X. Conversely, if the estimated coefficients of lagged Y in equation 2.1 are not statistically different from zero as a group (i.e., the null hypothesis: $\beta_1 = \beta_2 = \cdots = \beta_l = 0$ cannot be rejected), while at least one of the estimated coefficients of lagged X in equation 2.2 is statistically different from zero as a group (i.e., the null hypothesis: $\gamma_1 = \gamma_2 = \cdots = \gamma_l = 0$ can be rejected), then there is a unidirectional Granger causality from X to Y. Whereas, if at least one of the estimated coefficients of lagged Y in equation 2.1 is statistically different from zero as a group (i.e., the null hypothesis: $\beta_1 = \beta_2 = \cdots = \beta_l = 0$ can be rejected), while at least one of the estimated coefficients of lagged X in equation 2.2 is statistically different from zero as a group (i.e., the null hypothesis: $\gamma_1 = \gamma_2 = \cdots = \gamma_l = 0$ can be rejected), then there is a bilateral Granger causality between X and Y. Finally, if the estimated coefficients of lagged Y in equation 2.1 are not statistically different from zero as a group (i.e., the null hypothesis: $\beta_1 = \beta_2 = \cdots = \beta_l = 0$ cannot be rejected), while the estimated coefficients of lagged X in equation 2.2 are not statistically different from zero as a group (i.e., the null hypothesis: $\gamma_1 = \gamma_2 = \cdots = \gamma_l = 0$ cannot be rejected) either, then there is no Granger causality between X and Y.

The validity of the zero restrictions on the estimated β_i's and γ_i's are normally tested by performing an F test. For instance, to test the hull hypothesis that the group of the estimated coefficients on lagged Y in equation 2.1 are jointly statistically not different from zero (i.e., $\beta_1 = \beta_2 = \cdots = \beta_l = 0$), F statistic is calculated as:

$$F = \frac{(RSS_R - RSS_{UR})/(m_{UR} - m_R)}{RSS_{UR}/(n - m_{UR})}$$

where, RSS represents residual sum of squares, n is the total number of observations, m is number of coefficients in the estimated equation, and subscript R and UR represent restricted and unrestricted models. For instance, the F test of $\beta_1 = \beta_2 = \cdots = \beta_l = 0$ in equation 2.1, the restricted model is the regression without lagged Y, and the unrestricted model is the regression with lagged Y. This F statistic follows the F distribution with degrees of freedom $(m_{UR} - m_R)$ and $(n - m_{UR})$. If the computed F value exceeds the critical F value at the chosen level of significance, the null hypothesis should be rejected.

The F test as specified above is not applicable to non-stationary time series because the test is based on standard asymptotic theory which becomes invalid if the series contain stochastic trends (Park and Phillips, 1989, and Sims et al., 1990). Toda and Yamamoto (1995) propose a simple way to overcome this problem. Their procedure is applicable whether the variables in a VAR are stationary, integrated of an arbitrary order, or cointegrated of an arbitrary order. In a VAR consisting of potentially integrated or cointegrated variables, Toda and Yamamoto (1995) show that Granger causality test using zero restrictions on lagged terms are still valid, as long as the order of integration of the process does not exceed the true lag length of the model. In section 2.5.2, we adopt the Toda and Yamamoto's (1995) procedure to test Granger-causality between income, trade and pollution as follows:

(1) Test each variable to find the maximum order of integration: d.

(2) Estimate a VAR model in the levels of the variables, and determine the optimum lag length: p. Make sure the VAR is well-specified and there is no serial correlation in the residuals.

(3) Estimate a lag-augmented VAR model with $p + d$ lags, as follows:

$$Y_t = c_1 + \alpha_{1,1}Y_{t-1} + \cdots + \alpha_{1,p}Y_{t-p} + \cdots + \alpha_{1,p+d}Y_{t-p-d} + \beta_{1,1}E_{t-1} + \cdots + \beta_{1,p}E_{t-p} + \cdots + \beta_{1,p+d}E_{t-p-d} + \gamma_{1,1}O_{t-1} + \cdots + \gamma_{1,p}O_{t-p} + \cdots + \gamma_{1,p+d}O_{t-p-d} + e_t \quad (2.3)$$

$$E_t = c_2 + \alpha_{2,1}Y_{t-1} + \cdots + \alpha_{2,p}Y_{t-p} + \cdots + \alpha_{2,p+d}Y_{t-p-d} + \beta_{2,1}E_{t-1} + \cdots + \beta_{2,p}E_{t-p} + \cdots + \beta_{2,p+d}E_{t-p-d} + \gamma_{2,1}O_{t-1} + \cdots + \gamma_{2,p}O_{t-p} + \cdots + \gamma_{2,p+d}O_{t-p-d} + u_t \quad (2.4)$$

$$O_t = c_3 + \alpha_{3,1}Y_{t-1} + \cdots + \alpha_{3,p}Y_{t-p} + \cdots + \alpha_{3,p+d}Y_{t-p-d} + \beta_{3,1}E_{t-1} + \cdots + \beta_{3,p}E_{t-p} + \cdots + \beta_{3,p+d}E_{t-p-d} + \gamma_{3,1}O_{t-1} + \cdots + \gamma_{3,p}O_{t-p} + \cdots + \gamma_{3,p+d}O_{t-p-d} + v_t \quad (2.5)$$

where, Y is an indicator of income, such as GDP per capita; E is a measure of pollution, such as CO_2 and SO_2 emissions per capita; O is an indicator of trade, such as trade openness ratio; c_1, c_2, and c_3 are constants; e_t, u_t, and v_t are error terms; α, β, and γ, are regression coefficients.

(4) Test Granger causality between the variables using standard F tests for the first p lags, excluding the extra d lags. For instance, to test if "Z does not

Granger cause Y" is to test the null hypothesis of $H_0: \beta_{1,1} = \cdots = \beta_{1,p} = 0$ which can be done using a standard F test.

Toda and Yamamoto (1995) points out that the F test statistic computed in the last step of their procedure is asymptotically chi-square distributed.

2.4.3 Testing the EKC

The EKC regression equation, as used by Grossman and Krueger, (1991, 1993, and 1995); Shafik and Bandyopadhyaya, (1992); Panayotou, (1993); Selden and Song, (1994), is typically specified as follows:

$$E_{it} = c_{it} + \beta_2 Y_{it} + \beta_2 Y_{it}^2 + \varepsilon_{it} \qquad (2.6)$$

where, E is an environmental indicator, such as CO_2 and SO_2 emissions per capita; Y is a measure of income, e.g. GDP per capita; c is constant term; β are regression coefficients; subscript $i = 1, \dots, N$ denotes countries, $t = 1, \dots, T$ represents time period, and ε is the error term.

De Bruyn and Opschoor (1997) and Sengupta (1997) among others find that environmental degradation starts increasing again after deceasing to a certain point, so they propose that the relationship between income and pollution is N-shaped instead of being inverted U-shaped Echoing this argument, de Bruyn and Heintz (2002) criticise the standard reduced-form EKC equation as being inadequate, because it only includes the square term of income, thereby restricting the possible outcome to an inverted U-shaped, U-shaped or linear EKC. De Bruyn and Heintz (2002) propose an alternative specification as follows:

$$E_{it} = c_{it} + \beta_1 Y_{it} + \beta_2 Y_{it}^2 + \beta_3 Y_{it}^3 + \varepsilon_{it} \qquad (2.7)$$

With the addition of the cubic term, the relationship between income and pollution can potentially take seven distinct forms:

1. If $\beta_1 > 0$ and $\beta_2 = \beta_3 = 0$, pollution will increase monotonically as income rises.
2. If $\beta_1 < 0$ and $\beta_2 = \beta_3 = 0$, pollution will decrease monotonically as income rises.
3. If $\beta_1 > 0$, $\beta_2 < 0$ and $\beta_3 = 0$, pollution will follow an inverted U-shaped curve as income rises..
4. If $\beta_1 < 0$, $\beta_2 > 0$ and $\beta_3 = 0$, pollution will follow a U-shaped curve as income rises..
5. If $\beta_1 > 0$, $\beta_2 < 0$ and $\beta_3 > 0$, pollution will follow an N-shaped curve as income rises..

6. If $\beta_1 < 0$, $\beta_2 > 0$ and $\beta_3 < 0$, pollution will follow an inverted N-shaped curve as income rises..
7. If $\beta_1 = \beta_2 = \beta_3 = 0$, pollution will be independent of changes in income.

2.4.4 International trade and the EKC

This section reviews empirical models that investigate the environmental impact of international trade within the framework of the EKC. Four major studies on this issue are discussed in sections 2.4.4.1–2.4.4.4 in order of their time of publication. These studies are: Grossman and Krueger (1991), Suri and Chapman (1998), Cole (2004), and Kearsley and Riddel (2010).

2.4.4.1 Grossman and Krueger (1991)

Similar to other studies published around the same time (e.g., Shafik and Bandyopadhyay, 1992), Grossman and Krueger (1991), examine the environmental impact of international trade by introducing into the EKC equation a measure of international trade. The EKC regression equation thus becomes:

$$E_{it} = c_{it} + \beta_1 Y_{it} + \beta_2 Y_{it}^2 + \beta_3 Y_{it}^3 + \beta_4 O_t + \varepsilon_{it} \qquad (2.8)$$

Grossman and Krueger (1991) experimented with using the trade openness ratio as the trade indicator *O*.

As there is only one trade variable in the regression equation, the coefficient β_4 reflects the net impact of trade on pollution through all channels: the trade-induced scale, technique, and composition effects. As discussed in earlier sections, if the expansion of trade enhances income growth, the trade-induced scale effect tends to increase pollution. If trade promotes technological advances, the trade-induced technique effect tends to reduce pollution. The sign of the trade-induced composition effect is theoretically ambiguous. The pollution haven hypothesis (PHH) predicts that trade will raise pollution in developing countries but reduce pollution in developed countries. The factor endowment hypothesis (FEH) argues that the opposite is true: as trade between developing and developed countries expands, pollution will fall in the former but rise in the latter. For any particular country, therefore, the sign of coefficient β_4 cannot be known *a priori*. In the context of developing countries, if the technique effect and FEH-type composition effect dominate the scale effect and PHH-type composition effect, pollution should decline with growth in trade and β_4 should therefore be negative.

2.4.4.2 Suri and Chapman (1998)

One obvious limitation of the Grossman and Krueger (1991) approach is that it does not allow the net environmental impact of trade to be broken down into its components. Similarly, the technique and composition effects of income growth on the environment cannot be disentangled because they are jointly captured by the squared and cubed terms of income in the model. An attempt to address the problem is made by Suri and Chapman (1998) who add to the standard EKC equation new variables measuring trade in pollution-intensive goods and structural changes in the production mix of the economy. Suri and Chapman (1998) estimate the following equation:

$$E_{it} = c_{it} + \beta_1 Y_{it} + \beta_2 Y_{it}^2 + \beta_3 Y_{it}^3 + \beta_4 O_{it} + \beta_5 MS_{it} + \beta_6 MM_{it} + \beta_7 XM_{it} + \varepsilon_{it} \quad (2.9)$$

where MS is the share of manufacturing output in GDP; [23] MM is the ratio of manufacturing imports to domestic manufacturing output; XM is the ratio of manufacturing exports to domestic manufacturing output. The other variables in the equation are as previously defined. [24]

In Suri and Chapman (1998) specification, the GDP share of manufacturing, MS, represents the composition effect. Its coefficient β_5 is expected to be positive since pollution rises as the share of pollution-intensive production increases. XM reflects the degree of specialisation in pollution-intensive production, so its coefficient β_7 is expected to be positive since rise in pollution-intensive exports increases pollution. Whereas, MM reflects the degree of dirty domestic consumption supplied by imports, thus β_6 is expected to be negative since more dirty domestic consumption is met by foreign production lead to less domestic production pollution. If the PHH holds, XM in developing countries will rises as developing countries open up to trade and export more dirty goods to developed countries. If the FEH holds, MM in developing countries will rise since developing countries import more dirty goods from developed countries for domestic consumption as they open up to trade.

2.4.4.3 Cole (2004)

Suri and Chapman's (1998) approach implicitly assumes that all manufacturing activities are pollution-intensive. This assumption neglects the fact that some manufacturing industries are not heavily polluting. Hettige et al. (1995) study the

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[23] Suri and Chapman (1998) surmise that manufacturing activities are more pollution-intensive than services and agriculture. However, Stern (2002) finds that service industries may cause more SO_2 emissions than manufacturing.

[24] In Suri and Chapman's (1998) original specification, trade openness is not included in the regression. We introduce trade openness to our estimation following Cole's (2004) argument that trade openness captures the other effects, such as trade induced scale effect and trade induced technology effect, after controlling for dirty imports and exports.

pollution intensities of different industries and conclude that the three sectors of the International Standard Industrial Classification of All Economic Activities (ISIC)[25] with the lowest pollution intensities are: "textile, wearing apparel and industries" (ISIC 32), "manufacture of fabricated metal products" (ISIC 38) and "other manufacturing products" (ISIC 39), while the most pollution intensive sectors are "manufacture of wood and wood products" (ISIC 34), "manufacture of chemicals and chemical products" (ISIC 35), "manufacturing of non-metallic mineral products" (ISIC 36) and "basic metal industries" (ISIC 37). Following Hettige et al.'s (1995) classification of dirty sectors in manufacturing, Cole (2004) redefines dirty exports and imports and improves Suri and Chapman's (1998) specification as follows:[26]

$$E_{it} = c_{it} + \beta_1 Y_{it} + \beta_2 Y_{it}^2 + \beta_3 Y_{it}^3 + \beta_4 O_{it} + \beta_5 MS_{it} + \beta_6 DM_{it} + \beta_7 DX_{it} + \varepsilon_{it} \qquad (2.10)$$

where DM is the share of dirty imports from non-OECD countries in total imports; DX is the share of dirty exports to non-OECD countries in total exports;[27] the other variables in the equation are as previously defined.

As in Suri and Chapman (1998), the share of manufacturing in GDP, MS, in the above equation captures the composition effect, and coefficient β_5 is expected to be positive. The trade openness ratio, O, and the export and import shares of pollution intensive products to and from developing countries, DX and DM, all capture the environmental impact of international trade.[28] If the pollution haven effect dominates factor endowment effect, OECD countries will increasingly specialise in clean industries. As they export proportionately fewer dirty goods to and import proportionately more dirty goods from developing countries, their pollution emissions fall. Thus, the pollution level in OECD countries, E, is expected to increase with DX and decrease with DM. In other words, the coefficient β_7 is expected to be positive, and β_6 is expected to be negative. The trade openness ratio variable, O, represents the remaining environmental impact of trade after controlling for trade-induced composition effect. As discussed earlier, it can be considered a catch-all term for trade-induced scale and technique effects, so the β_4 may be positive or negative.

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[25] Hettige et al (1995) use ISIC Rev. 2, available on the World Bank website at http://unstats.un.org/unsd/cr/registry/regcst.asp?cl=8

[26] Cole (2004) uses GNP per capita at market exchange rates as the indicator of income level. To make meaningful comparison across countries, we use Purchasing Power Parity adjusted GDP per capita as our indicator of income level.

[27] Because our study focuses on four developing countries, we redefine DM as the share of dirty imports from OECD countries in total imports and DX as the share of dirty exports to OECD countries in total exports.

[28] The sample in Cole (2004) consists of exclusively OECD countries. Therefore, the discussion here is carried out from the standpoint of developed countries. But our discussion can be easily adapted for developing countries, as we do in section 2.5.5.

Moreover, it may also be meaningful to distinguish between two scenarios, i.e. pollution haven effect dominates factor endowment effect (PHE > FEE) and factor endowment effect dominates pollution haven effect (FEE > PHE). If PHE > FEE, DX should be reducing and DM should be increasing over time in developed countries, since developed countries specialise in producing clean goods and import dirty goods. In contrast, if FEE > PHE, DX should be rising and DM should be reducing over time in developed countries, since developed countries specialise in producing dirty goods and import clean goods. For developing countries, ($DX \uparrow, DM \downarrow$) indicate FEH < PHH, and ($DX \downarrow, DM \uparrow$) indicate FEH > PHH.

<u>2.4.4.4 Kearsley and Riddel (2010)</u>

Kearsley and Riddel (2010) contend that the regression analysis in Cole (2004) is carried out on trade variables too highly aggregated to yield informative results. They argue that the different manufacturing activities classified as pollution intensive industries in Cole (2004) may well have different marginal effects on pollution emissions. By lumping them together to calculate dirty exports and imports shares, DX and DM, Cole (2004) imposes an implicit restriction of uniform marginal effect across all dirty industries. Citing Hettige et al. (1995), Kearsley and Riddel (2010) maintain that there is at least prima facie evidence that the restriction is not sustained by trade data and, as a result, the EKC model in Cole (2004) is misspecified. Furthermore, they argue that the misspecification may not only obscure the environmental impact of trade flows in pollution-intensive manufactures, but also bias the parameter estimates of the other variables in the EKC equation. The solution proposed by Kearsley and Riddel (2010) is to disaggregate the pollution-intensive manufacturing sector into a number of subsectors, and then calculate DX and DM for each subsector. The EKC model in Kearsley and Riddel (2010) takes the following form:

$$E_{it} = \beta_0 + \beta_1 Y_{it} + \beta_2 Y_{it}^2 + \beta_3 MS_{it} + \beta_4 O_{it} + \sum_{k=1}^{n} \theta_k DX_{it}^k + \sum_{k=1}^{n} \delta_k DM_{it}^k + \gamma_i + \lambda_t + \varepsilon_{it} \qquad (2.11)$$

where, *i* is the country index, n is the number of subsectors into which the industries falling under ISIC codes 31 through 39 can be classified; *k* is the subsector index; DX_{it}^k is the share in total exports of dirty exports from subsector *k* to all non-OECD countries for OECD country *i*; the parameters θ_k and δ_k represent the marginal effects on pollution emissions of dirty exports and imports in subsector *k*, respectively. It is clear that, since the θ_k's (δ_k's) are not restricted to take the same value, the foregoing specification of the EKC leaves some room for heterogeneity in the environmental impact of different dirty industries.

In section 2.5.5, we fit our data to the three specifications proposed respectively by Grossman and Krueger (1991), Suri and Chapman (1998) and Cole (2004) to study the impacts of trade on pollution and the shape of the EKC in the BASIC bloc. We do not, however, explore the modification suggested by Kearsley and Riddel (2010) to the Cole (2004) specification. The availability of information about trade flows at the ISIC 2-digit level or below is limited for the four countries. We have 18 years of data for China, 22 years for Brazil and South Africa, and 26 years for India. Thus, even disaggregation to the ISIC 2-digit level will leave us with too few degrees of freedom for our regression analysis.

2.4.5 Data

A multitude of pollutants exist. Some pollutants cause damage to public health and the ecological system mainly in areas near the source of emission. They are known as local pollutants. Examples of local pollutants are sulphur dioxide (SO_2), volatile organic compounds and particulate matter. In contrast to local pollutants, anthropogenic emissions of greenhouse gases such as carbon dioxide (CO_2), methane, nitrous dioxide, and so on lead to global warming and climate change. Greenhouse gases, along with a number of other pollutants whose environmental impact has a global reach, are sometimes referred to as global pollutants. The accumulated evidence from environmental studies indicates that different types of pollutant tend to follow different trajectories over time. An EKC-type relationship is widely found to exist for a number of local water and air pollutants, such as SO_2 emissions and sewage. There is, however, much less evidence in support of an EKC for such global pollutants as CO_2 emissions (Levinson, 2000; and Yandle et al., 2004).

The empirical analysis in this chapter exclusively focuses on one global pollutant – CO_2, and one local pollutant – SO_2. The two pollutants have been extensively used in empirical studies as typical global and local pollutants, respectively (e.g., Dasgupta et al., 2002; Perman and Stern, 2003; Dinda, 2004; Vollebergh et al., 2005; Galeotti et al 2006; He, 2007; and Carson 2010). However, our omission of other pollutants, some of which have more damaging environmental effects than CO_2 and SO_2, is first and foremost conditioned by the availability of data. For instance, biochemical oxygen demand (BOD) is the measure commonly used to indicate organic water pollution. For the four countries in question, the BOD series we obtained cover the period of 1980–2002 only, with many missing observations for Brazil. The particulate matter series

(PM10) are of an even shorter span of 1990–2009. The nitrous oxide emission series are only available every 5 years from 1990 to 2005.

2.4.5.1 Carbon Dioxide (CO_2)

As a typical global pollutant, carbon dioxide (CO_2) has been studied extensively by previous research, since it is one of the main components in the Greenhouse Gases (GHG). It is estimated that CO_2 can contribute up to 26% of the GHG (Kiehl and Trenberth, 1997). It can be seen that world CO_2 concentration has been rising since 1750, and dramatically shot up after the industrial revolution. So it is widely believed that the rise of CO_2 concentration on the earth is significantly contributed by human activities, such as fossil-fuel burning, hydraulic cement production and gas flaring (Boden et al., 1995 and Andres et al., 1999).

Our annual CO_2 data are sourced from the World Bank's World Development Indicators (WDI) 2014, and are estimated following the approach proposed by Boden et al. (1995) and Andres et al. (1999), who argue that since fossil-fuel burning, hydraulic cement production and gas flaring are the main anthropogenic sources of CO_2, the national CO_2 should be estimated from these three sources. Their estimation methods are as follows.

Fossil-fuel has been used as human's major energy source for a long history since the industrial revolution. Fossil-fuel including solid fuels (i.e. coal, brown coal and peat), liquid fuels (i.e. crude oil) and gaseous fuels (i.e. natural gas), contents high percentage of carbon. For this reason, fossil-fuel burning (or combustion) is the main cause of the world's CO_2 emissions (more than 95% of the global total). The estimation methodology of CO_2 emissions from fossil-fuel burning by Boden et al. (1995) and Andres et al. (1999) is:

$$CO_{2i} = P_i \times FO_i \times C_i \qquad (2.12)$$

where, subscript i represents a particular fossil fuel commodity, P represents the quantity of fuel i combusted, FO represents the fraction of P that is oxidised, C represent the average carbon content for fuel i, and CO_2 represent the CO_2 emissions resulting from fuel i.

At national level, the CO_2 emissions are estimated using fossil fuel consumption as quantity of fossil fuel combusted, because the CO_2 emissions should be generated from one country's real consumption of fossil fuel correcting for fuel trade, bunkers consumption and changes in stocks. So the national fossil fuel consumption is calculated following the apparent consumption approach as:

$$consumption_i = production_i + imports_i - exports_i - bunkers_i - changes\ in\ stocks_i \quad (2.13)$$

where, subscript i represents a particular fossil fuel commodity, production is the quantity of fuel i produced, $imports$ is the quantity of fuel i imported, $exports$ is the quantity of fuel i exported, $bunkers$ represents the quantity of fuel i consumed by ships and aircraft engaged in international trade, $changes\ in\ stocks$ represents the quantity changes of fuel i at producers, importers, and/or industrial consumers from the beginning to the end of each year.

Carbon contents and oxidised fractions are assumed to be fairly consistent, but a positive or negative 1% to 3% variation rate is allowed according to each commodity to serve the purpose of pursuing an accurate estimation[29]. Particularly, the oxidised fractions are estimated under the assumption that no end-of-pipe abatement is applied. The limitation of this assumption may include: firstly, it may be the case that the end of pipe abatement technology is different between BASIC countries, but we fail to find any existing study. Moreover, it is unlikely that the end-of-pipe abatement technology and its extensiveness of adoption are consistent over time, so it may be improper to assume that oxidised fractions are fixed over countries and time. Therefore, it is likely that the assumption of country- and time-invariant oxidised fraction will bias the estimates of CO_2 emissions.

Another industrial source of CO_2 is the calcination of calcium carbonate in the cement manufacturing, because in the cement producing process, one unit of calcium carbonate ($CaCO_3$) is broken down into one unit of calcium oxide (CaO) and one unit of CO_2. Therefore, the CO_2 emissions from cement manufacturing can be consistently estimated, due to the equality between the amount of CaO retained in cement and CO_2 released into air. Another source of CO_2 is the flaring of natural gas in the oil field, for eliminating excess gases during unexpected equipment failures or plant emergencies. The CO_2 emissions from cement manufacturing and natural gas flaring contribute 3% and 1% respectively to the world's total emissions. Compare to the CO_2 emissions from fossil fuel, 95% of the world's total, both the CO_2 emissions from cement manufacturing and natural gas flaring are far less.

Overall speaking, the World Bank's CO_2 emissions data may be biased due that they fail to consider the CO_2 emissions caused by biofuels[30], oxidation of nonfuel

[29] Detailed information is in Boden et al (1995).
[30] Biofuel's CO_2 emissions is excluded intentionally to avoid the risk of double counting, albeit it should be included in a complete accounting of CO_2 emissions.

products, and deforestation. Particularly, it is likely that Brazil and South Africa's CO_2 emissions are bias estimated. Since Brazil has massive amazon rainforest, missing estimation for CO_2 emissions caused by deforestation is likely to cause larger errors in Brazil's CO_2 emissions data. Because Botswana, Lesotho, Namibia, South Africa and Swaziland, are in the South Africa Customs Union (SACU), and there is no international trade statistics available between these five countries. The World Bank's estimation hypothetically assumes all energy source trade is attributed to South Africa, which is the most populated nation (86% of total population in SACU). This leads to a possible bias estimation for the CO_2 emissions in South Africa.

Although the World Bank's CO_2 emissions data are originally sourced from the Carbon Dioxide Information Analysis Center (CDIAC), who estimates the national CO_2 emissions data for 240 countries in the world covering the period 1750 – 2010, we only focus on the period 1950-2010 due to our data limitations for other variables. Detail descriptive statistics of our CO_2 emissions per capita data are reported in table 2.3, and line graphs are showed in figure 2.4. From 1960 to 2010, per capita CO_2 emissions in Brazil, China, India and South Africa have shown a clearly increasing trend. However, comparing with four developed countries, except South Africa, Brazil, China and India all have much lower per capital CO_2 emissions. Our data shows that in aggregate Brazil, China, India and South Africa are world top emitters, ranking 17th, 1st, 3rd and 13th respectively in the world, but in per capita term, Brazil, China and India have still relatively low level of per capita CO_2 emissions comparing to developed countries.

In four BASIC countries, Brazil's CO_2 emissions per capita first increased until 1979, when the energy crisis occurred (oil shock); after which, Brazil's CO_2 emissions per capita fluctuated at a relatively lower level, and then sharply increased again after 1994, when the 'Real Plan' initiated. Whereas, China's per capita CO_2 emissions experienced steady growth since China's economic reform in the late 1970s, and then shot up sharply since early 2000s, when China jointed the WTO and its economy maintained fast growth. In the case of India, per capita CO_2 emissions rose steadily and linearly over the period 1960 to 2010 as India economy grew. Comparing to the other three BASIC countries, South Africa had the highest level of per capita CO_2 emissions from 1960 to 2010, which had experienced significantly reduce during the disinvestment period 1980s-1990s, when South Africa was facing the international sanctions. Generally, we find that footprints of per capita CO_2 emissions in four BASIC countries reflect their economic histories. In contrast, per capita CO_2 emissions in three developed countries: France, the U.K., and the US, reached peak levels in the 1970s, and gradually dropped since then, but still at much higher levels than four BASIC countries. These figures again show that the high level of aggregate CO_2 emissions in BASIC countries should be attributed to their population problem. There is no evidence that peak levels of per capita CO_2 emissions are reached in BASIC countries, except South Africa, who may have reached a peak per capita CO_2 emissions level at 1984, but it rose again after 2002.

Table 2.3 Descriptive statistics of CO_2 emissions per capita in the BASIC and selected four developed countries (1960–2010)

CO_2 p.c.	Brazil	China	India	South Africa
Mean	1399.6600	2170.5460	738.8198	8283.0220
Median	1436.3500	1871.0550	627.4044	8392.5750
Maximum	2150.2680	6194.8580	1666.2090	10357.1500
Minimum	644.5578	574.1621	268.2010	5629.7180
Std.Dev.	417.5725	1425.5030	397.8810	1395.7660
Skewness	-0.3892	1.1890	0.6742	-0.3429
Kurtosis	2.1913	3.7795	2.3796	2.0184
Jarque–Bera	2.6775	13.3071	4.6813	3.0468
Probability	0.2622	0.0013	0.0963	0.2180
Sum	71382.67	110697.90	37679.81	422434.10
Sum Sq.Dev.	8718338	102000000	7915464	97408115
Observations	51	51	51	51

CO_2 p.c.	France	Germany	UK	US
Mean	7155.5090	10193.2500	10125.2000	19369.1500
Median	6830.3310	10096.6800	10034.6400	19464.2900
Maximum	9703.3870	11622.6500	11823.0400	22510.5800
Minimum	5516.3470	8940.5120	7686.4520	15681.2600
Std.Dev.	1183.9940	655.5957	1031.3760	1543.2920
Skewness	0.7528	0.0722	-0.1951	-0.4037
Kurtosis	2.3809	2.8214	2.2842	3.1392
Jarque–Bera	5.6319	0.0440	1.4123	1.4268
Probability	0.0598	0.9783	0.4936	0.4900
Sum	364931.00	203864.90	516385.30	987826.50
Sum Sq.Dev.	70092083	8166309	53186859	119000000
Observations	51	20*	51	51

*CO2 p.c.: CO2 emissions per capita in kilograms. 'Std. Dev.' is standard deviation. 'Sum Sq.Dev.' is sum of squared deviations. * Germany data is from 1991 to 2010 only. Sourced from the World Bank's World Development Indicators (WDI) 2014.*

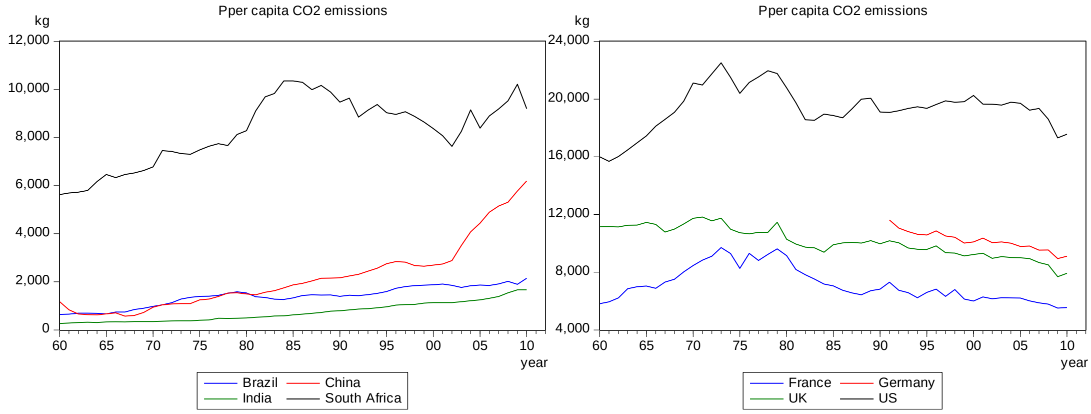

Figure 2.4 Per capita CO2 emissions in the BASIC and four developed countries
Sourced from the World Bank's World Development Indicators (WDI) 2014.

2.4.5.2 Sulphur Dioxide (SO_2)

Different from the CO_2, Sulphur Dioxide (SO_2) is a typical local pollutant, and it is also extensively studied by existing literature due to its serious detrimental impacts (see section 2.2.2.3). Smith et al. (2011) argue that the main anthropogenic sources of SO_2 emissions are fossil fuel combustion, international shipping, and metal smelting, in which the fossil fuel combustion contributes the largest share, 80% of the world total SO_2 emissions.

The SO_2 emissions from fossil fuel in Smith et al.'s (2011) data set are estimated by Smith et al. (2001) approach as follows:

$$SO_{2i} = \sum[P_i \times S_i \times (1 - f_{ash}) \times (1 - f_{control})] \qquad (2.14)$$

where, SO_2 represent the SO_2 emissions resulting from fuel i, subscript i represents a particular fossil fuel commodity, P represents the quantity of fuel i combusted, S represent the average sulphur content for fuel i, f_{ash} is the fraction of the sulphur retained in ash and $f_{control}$ is the fraction that is removed by emissions controls.

In Smith et al. (2001 and 2011)'s estimation of the SO_2 emissions, the term $(1 - f_{ash})$ is as the oxidised fraction in the CO_2 emissions estimation (see section 2.4.5.1), but the difference is that Smith et al. take into account the nations' SO_2 emissions reduction efforts as captured by the term $(1 - f_{control})$. The values of emissions control percentage are often sourced from the existing studies. For instance, Smith et al. apply a 3% control rate for China's SO_2 emissions due to China's coal washing and emissions reduction efforts as reviewed by Baoming (1994) and Qi et al. (1995), but assume no emissions controls for the rest of developing Asia.

The SO_2 emissions from the international shipping are estimated from the shipping fuel consumption. Whereas the SO_2 emissions from the metal smelting are estimated from the difference between gross sulphur content of ore and the smelter sulfuric acid production. The SO_2 emissions from the international shipping and metal smelting contribute respectively 5% and 15% of the world total SO_2 emissions.

The limitation of Smith et al.'s (2011) SO_2 emissions data may include. Firstly, sulfur removals are often not reported by nations, which may be significant SO_2 emissions reduction efforts in some countries. Secondly, the end-of-pipe abatement technology and its extensiveness of adoption are all important factors that influence BASIC bloc's SO_2 emissions, so ignoring or assuming fixed rates for them across countries and over time may bias the SO_2 emissions estimation.

Although Smith et al.'s (2011) provide a rich SO_2 emissions data set for world nations for the period 1850-2005, we exclusively focus on the SO_2 emissions in the BASIC bloc of the period 1960-2005 due to our data limitations for other variables. Our annual per capita SO_2 emissions data are calculated by dividing the aggregate national annual SO_2 emissions by the total national population sourced from the World Bank's World Development Indicators (WDI) 2014.

The detail descriptive statistics of our per capita SO_2 emissions data are reported in table 2.4, and line graphs are showed in figure 2.5. Per capital SO_2 emissions in Brazil and South Africa first went up until the late 1970s, when the oil shock occurred, since which per capital SO_2 emissions have steadily decreased. However, in the case of China and India, per capital SO_2 emissions have exhibited linearly increasing trend over the period 1960-2005. Particularly, China's per capita SO_2 emissions have increased more sharply since early 2000s, after China's accession to WTO.

In sum, first of all it has been seen clear evidence that global pollutant: CO_2 emissions and local pollutant: SO_2 emissions, exhibited different patterns in the BASIC bloc. Over the period 1960 to 2010, per capital CO_2 and SO_2 emissions in Brazil and South Africa have shown an inverted U shape trend against time, but in China and India have shown a linearly increasing trend. Secondly, footprints of per capita CO_2 and SO_2 emissions seem to be influenced by economic histories in the BASIC bloc. Lastly, it may be worth noting that per capital CO_2 and SO_2 emissions in China have experienced significantly sharper rises after China's accession to WTO.

The limitation of our CO_2 and SO_2 emissions data may also include. First, all our CO_2 and SO_2 emissions data are estimated from human activities, mainly from fossil fuel combustion. Our data do not take into account many emissions reduction efforts, such as the end-of-pipe abatement technology and its extensiveness of adoption, at the same time do not consider other sources of emissions, such as deforestation, biofuels combustion, and oxidation of nonfuel products. Moreover, CO_2 and SO_2 emissions are just two of many pollutants generated by human activities, so it may not be proper to use them to represent all other pollutants, since their trend may not necessarily represent the general trend of all pollutants. The emissions of different pollutants do not necessarily move in tandem, and there may be a certain degree of substitutability between some pollutants. For example, diesel-powered cars emit less greenhouse gases than do petrol cars, but diesel engines produce far more local air pollutants, such as nitrogen oxides, particulate matter and smoke. Therefore, one must be cautious not to equate “carbon/sulphur intensive” with “pollution intensive” or read a change in CO_2/SO_2 emissions as a change in overall pollution.

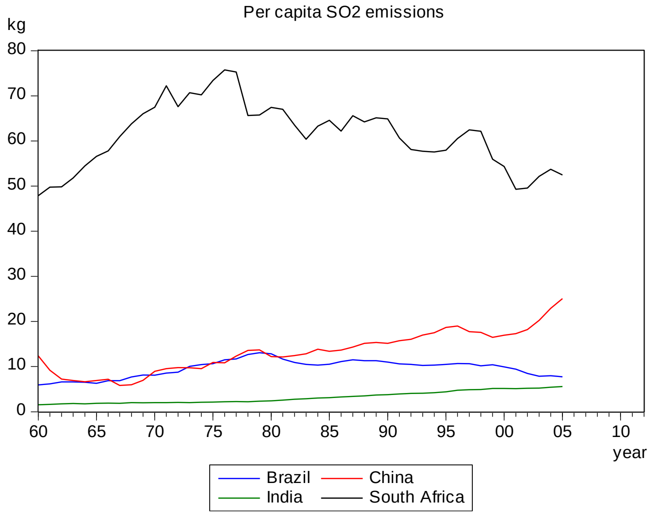

Figure 2.5 Per capita SO2 emissions in the BASIC

Table 2.4 Descriptive statistics of SO_2 emissions per capita in the BASIC (1960–2005)

SO_2 p.c.	Brazil	China	India	South Africa
Mean	9.6037	13.2842	3.1746	61.2136
Median	10.3308	13.4777	2.8226	62.1640
Maximum	13.0850	25.0617	5.5667	75.7510
Minimum	5.9568	5.8227	1.5613	47.8948
Std.Dev.	1.9399	4.6044	1.2974	7.2620
Skewness	-0.3582	0.2609	0.4732	-0.0138
Kurtosis	2.0859	2.5998	1.7417	2.2652
Jarque–Bera	2.5851	0.8289	4.7516	1.0364
Probability	0.2746	0.6607	0.0929	0.5956
Sum	441.7695	611.0748	146.0313	2815.8250
Sum Sq.Dev.	169.3515	954.0372	75.7466	2373.1340
Observations	46	46	46	46

SO_2 p.c.: SO_2 emissions per capita in kilograms.
‘Std. Dev.’ is standard deviation; ‘Sum Sq.Dev.’ is sum of squared deviations.

2.4.5.3 GDP

Our annual GDP per capita data are from the World Bank’s World Development Indicator 2014. Our GDP data are adjusted by the Purchasing Power Parity (PPP) in the unit of constant 2000 price international dollar GDP. The descriptive statistics of the series are reported in table 2.5, and line graphs are showed in figure 2.6. In this chapter unless specified otherwise, the “$” sign refers to constant 2000 price international dollar.

From 1960 to 2012, Brazil’s GDP per capita first sharply shot up from $3479 (1960) to $8498 (1980), then fluctuated at a level around $8,000, and then significantly went up after the ‘Real Plan’ in 1994. The per capita GDP in China and India grew steadily in the figure 2.6, exhibiting the fast economic growth miracles in China and India as discussed by many media and research papers. In China and India, GDP per capita grew rapidly from $333 and $774 in 1960 to $8939 and $3753 in 2012, respectively. South Africa’s per capita GDP experienced slow yet steady growth from 1960 to the early 1980s. From the early 1980s to the mid-1990s, international sanctions against the apartheid regime caused considerable economic strain in South Africa, shaving nearly $1,000 off per capita GDP. The end of Apartheid in 1994 saw economic growth return to the country, and per capita GDP has since been growing steadily.

Table 2.5 Descriptive statistics of GDP per capita in the BASIC (1960–2012)

GDP p.c.	Brazil	China	India	South Africa
Mean	7564.0170	2032.6870	1522.2700	8943.0500
Median	8047.0770	980.2641	1166.3540	8990.0950
Maximum	11529.9300	8939.0770	3752.6200	11076.1700
Minimum	3479.4930	228.3229	774.1874	6263.5230
Std.Dev.	2251.5090	2313.3960	820.3557	1085.6540
Skewness	-0.4277	1.5358	1.3245	-0.4521
Kurtosis	2.3426	4.3786	3.7395	3.4777
Jarque–Bera	2.5702	25.0333	16.7038	2.3098
Probability	0.2766	0.0000	0.0002	0.3151
Sum	400892.90	107732.40	80680.30	473981.70
Sum Sq.Dev.	264000000	278000000	34995139	61289490
Observations	53	53	53	53

GDP p.c.: GDP per capita in constant 2000 international dollar.
‘Std. Dev.’ is standard deviation; ‘Sum Sq.Dev.’ is sum of squared deviations.
Sourced from the World Bank’s World Development Indicators (WDI) 2014.

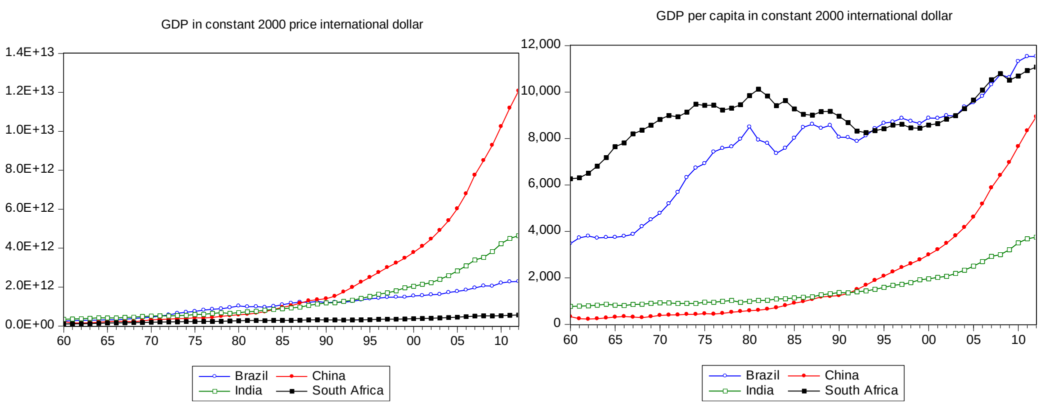

Figure 2.6: GDP and GDP per capita in the BASIC
GDP values are adjusted by PPP in 2000 international dollar. *Source: World Development Indicator 2014*

2.4.5.4 Trade openness

The indicator adopted in this chapter to measure a country's openness to international trade is the trade-to-GDP ratio. The ratio is calculated as the sum of imports and exports divided by GDP. Historical series of the ratio are directly available from the World Bank's World Development Indicators database (WDI 2014). The descriptive statistics of the trade openness series are reported in table 2.6, and line graphs are showed in figure 2.7.

Over the period 1960-2012, trade openness ratios in Brazil and South Africa went up slowly with many fluctuations, whereas trade openness ratios in China (1970-2012) and India experienced exponential growth. More specifically, Brazil's trade openness had fluctuated around 17% before the "Real Plan" was introduced in 1994, and then shot up. China's trade openness soared after China's accession to the World Trade Organisation (WTO) in the early 2000s. Before economic liberalisation, India's trade openness had increased relatively slowly for about three decades, but significantly rose after early 1990s, when India began her economic liberalisation. South Africa's trade openness dropped significantly from the early 1980s to the early 1990s when the international community imposed restrictions on trade with the country and a large number of foreign companies disinvested from it. . In general, trade openness increased in all four countries over the period of 1960–2012, with particularly pronounced rise observed in China and India.

In sum, the expansion of trade in the BASIC countries is representative of the rapid globalization the world economy has been going through over the last half century. At the same time, the increasing participation of the BASIC countries in the world economy also helped shape globalization at large. The implementation of the "Real Plan" in Brazil, economic reform in China, economic liberalization in India, and end of apartheid in South Africa are events that have exerted strong influence on the process of the individual economy's integration with the world economy. They have also affected the speed and pattern of trade integration at the global level.

Table 2.6 Descriptive statistics of the trade openness ratio in the BASIC (1960–2012)

Trade openness	Brazil	China	India	South Africa
Mean	18.4791	33.5786	20.3009	52.6165
Median	16.5909	31.6746	14.2572	52.7863
Maximum	28.9732	70.5671	55.3648	74.8235
Minimum	9.0577	5.3142	7.5297	38.6454
Std.Dev.	4.8458	19.0624	13.6527	6.7972
Skewness	0.4804	0.2694	1.3125	0.4305
Kurtosis	2.2860	2.0946	3.5081	4.0340
Jarque–Bera	3.1639	1.9889	15.7875	3.9981
Probability	0.2056	0.3699	0.0004	0.1355
Sum	979.3907	1443.8780	1075.9490	2788.6760
Sum Sq.Dev.	1221.0400	15261.7000	9692.5720	2402.4880
Observations	53	43*	53	53

Values of the trade openness series are expressed in percentage points.
'Std. Dev.' is standard deviation; 'Sum Sq.Dev.' is sum of squared deviations.
**China's openness data are only available from 1970.*
Sourced from the World Bank's World Development Indicators (WDI) 2014.

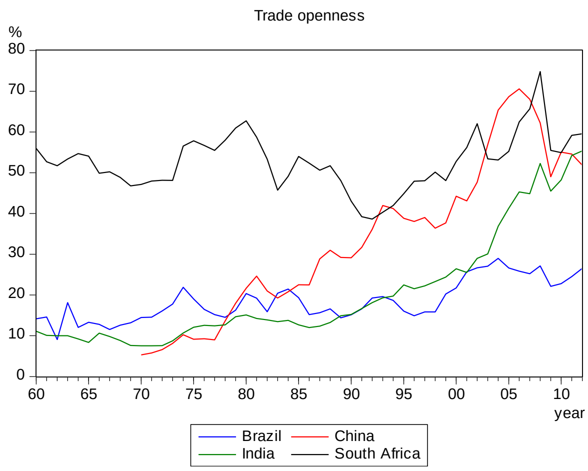

Figure 2.7 Trade openness ratio in the BASIC
Sourced from the World Bank's World Development Indicators (WDI) 2014.

2.4.5.5 Manufacturing share, exports and imports

As in reviewed in section 2.4.4.2, Suri and Chapman (1998) experiment with introducing new variables into the standard EKC curve to test the effects of trade on the relationship between income and pollution. The three additional variables included in their study are: the share of manufacturing output in GDP, the ratio of manufacturing imports to manufacturing output, and the ratio of manufacturing exports to manufacturing output. As the Suri and Chapman (1998) model is one of the specifications of the EKC to be tested in section 2.5, we also construct the three variables for the BASIC. The manufacturing share of GDP series are directly available from *World Development Indicators* (World Bank, 2014). The manufacturing imports ratio series are calculated as follows:

$$manufacturing\ imports = mechandise\ imports \times share\ of\ manufacturing\ imports\ in\ mechandise\ imports \quad (2.15)$$

$$manufacturing\ output = GDP \times share\ of\ manufacturing\ output\ in\ GDP \quad (2.16)$$

$$manufacturing\ imports\ ratio = manufacturing\ imports \div manufacturing\ output \quad (2.17)$$

The manufacturing exports ratio series are obtained similarly. All required data are sourced from *World Development Indicators* 2014.[31] The descriptive statistics of manufacturing share, manufacturing exports and imports ratios are reported in tables 2.7, 2.8, and 2.9, and line graphs are showed in figures 2.8 and 2.9 respectively.

As can be seen in figure 2.8, the manufacturing share of GDP in Brazil was relatively high historically. Having reached nearly 30% in the 1960s and 1970s, it was pushed up further by the industrialisation drive during 1974–1985. The Latin American debt crisis in the early 1980s ushered in a period of stagnation. Manufacturing share decreased sharply until the “Real Plan” in 1994 succeeded in stabilising the economy. In the post “Real Plan” period, the manufacturing share has hovered around 17%. In China, the contribution of manufacturing to GDP rose sharply in the 1960s and 1970s, hitting a peak in 1978 at 49.47%. Since the initiation of economic reform in the early 1980s, China’s manufacturing share had been on a downward trend but seems to have stabilised at a level around 33% in the last decade. In contrast to the large rises and falls

[31] The ratios of manufacturing exports and imports to domestic manufacturing output can exceed unity, especially in countries with a large amount of entrepot trade, because exports and imports data are mostly available in total value rather than value added terms (Suri and Chapman, 1998).

seen in Brazil and China, manufacturing share in India remained relatively constant at around 16% throughout the period 1960–2012. Staying at around 22%, South Africa's manufacturing share had exhibited similar stability until the early 1990s. Since then it has been declining slowly but continuously, reaching 12.38% in 2012.

As for the manufacturing imports and exports ratios, the most salient feature of figure 2.9 is the upward movements in both ratios in all four countries since the early 1990s. The most dramatic rises are found in China and India, partly because the two countries started from a relatively low level at the beginning of the period. However, significant increases can also be seen in Brazil and South Africa.

Table 2.7 Descriptive statistics of manufacturing share in BASIC countries (1960–2012)

	Brazil	China	India	South Africa
Mean	25.2456	33.9809	15.1801	20.6272
Median	27.2025	33.5698	15.3091	21.3501
Maximum	34.5600	40.4704	17.3135	23.9958
Minimum	13.2516	26.1213	12.4289	12.3836
Std.Dev.	6.6376	3.0419	1.0678	2.6691
Skewness	-0.3700	0.1573	-0.3749	-1.4003
Kurtosis	1.5757	3.2969	2.9420	4.6978
Jarque–Bera	5.5816	0.3586	1.2486	23.6873
Probability	0.0614	0.8359	0.5356	0.0000
Sum	1312.7690	1563.1220	804.5456	1093.2410
Sum Sq.Dev.	2246.9310	416.3980	59.2938	370.4580
Observations	52*	46**	53	53

Manufacturing share is expressed in percentage points.
'Std. Dev.' is standard deviation; 'Sum Sq.Dev.' is sum of squared deviations.
**Brazil's manufacturing share data for the year 1990 is missing.*
***China's manufacturing share data are missing for the period 1960-1964 and 2011-2012.*
Sourced from the World Bank's World Development Indicators (WDI) 2014.

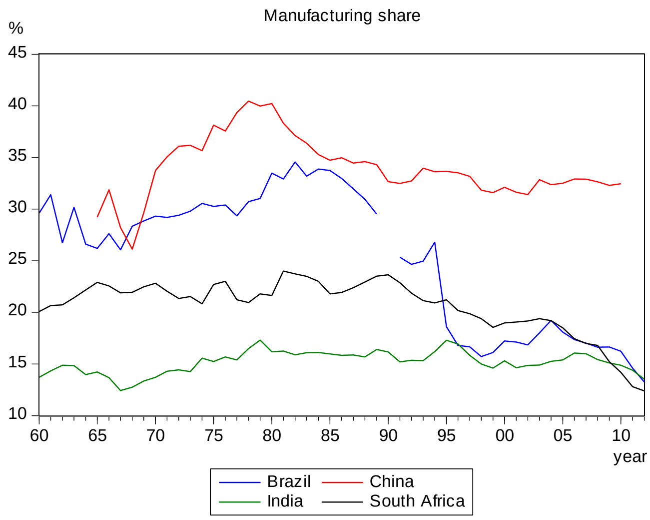

Figure 2.8 Manufacturing share in the BASIC
Sourced from the World Bank's World Development Indicators (WDI) 2014.

Table 2.8 Descriptive statistics of manufacturing imports ratio in BASIC countries (1960–2012)

	Brazil	China	India	South Africa
Mean	22.4611	44.1215	30.9824	86.2984
Median	16.1743	42.5943	23.8312	78.8956
Maximum	57.1478	67.5591	84.8781	160.3959
Minimum	7.0329	20.7263	12.0614	52.1428
Std.Dev.	13.7444	12.6374	19.0553	27.1016
Skewness	0.7135	-0.0138	1.4880	1.1395
Kurtosis	2.2206	2.6567	4.2280	3.7482
Jarque–Bera	5.5080	0.1335	21.5932	7.9114
Probability	0.0637	0.9354	0.0000	0.0191
Sum	1123.0530	1191.2790	1549.1180	2847.8470
Sum Sq.Dev.	9256.5180	4152.2840	17792.0900	23503.8300
Observations	50*	27**	50***	33****

Manufacturing imports ratio is in the unit of percentage.
'Std. Dev.' is standard deviation; 'Sum Sq.Dev.' is sum squared deviation.
**Brazil's data are missing for the year 1960, 1961 and 1990.*
***China's data are missing for the period 1960-1983 and 2010-2012.*
****India's data are missing for the year 1960, 1961 and 1982.*
****South Africa's ratio data are missing for the period 1960-1973 and 1986-1991.*
Sourced from the World Bank's World Development Indicators (WDI) 2014.

Table 2.9 Descriptive statistics of manufacturing exports ratio in BASIC countries (1960–2012)

	Brazil	China	India	South Africa
Mean	15.7992	54.0401	28.6850	51.7144
Median	14.8200	50.2834	18.7371	56.2131
Maximum	40.4349	100.2239	76.2223	91.9442
Minimum	0.5995	6.7869	9.4066	16.5487
Std.Dev.	12.0228	26.3379	18.4177	22.4727
Skewness	0.5278	0.0821	0.7975	-0.0860
Kurtosis	2.1520	2.3476	2.4894	1.8734
Jarque–Bera	3.8195	0.5092	5.9602	1.7318
Probability	0.1481	0.7752	0.0508	0.4207
Sum	789.9589	1459.0830	1462.9350	1654.8620
Sum Sq.Dev.	7082.8070	18035.7800	16960.5200	15655.7100
Observations	50*	27**	51***	32****

Manufacturing imports and exports ratio is in the unit of percentage.
'Std. Dev.' is standard deviation; 'Sum Sq.Dev.' is sum squared deviation.
**Brazil's data are missing for the year 1960, 1961 and 1990.*
***China's data are missing for the period 1960-1983 and 2010-2012.*
****India's data are missing for the year 1960 and 1961.*
****South Africa's data are missing for the period 1960-1973 and 1985-1991.*
Sourced from the World Bank's World Development Indicators (WDI) 2014.

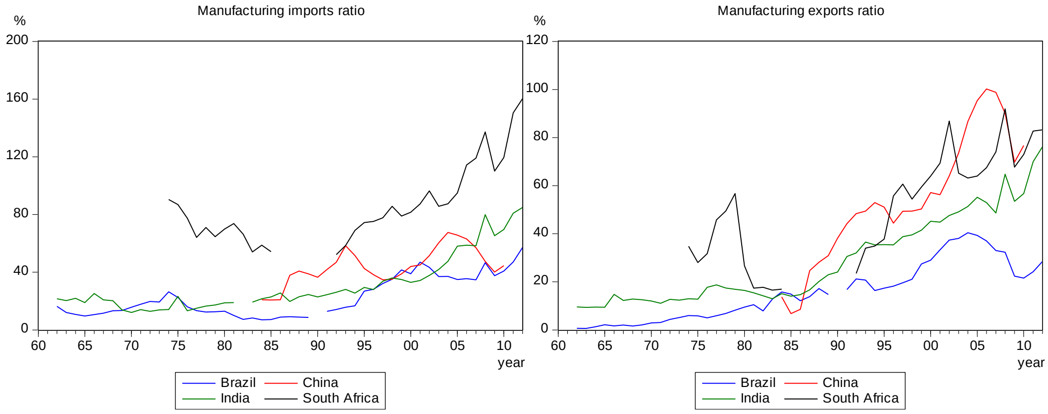

Figure 2.9 Manufacturing imports and exports ratios in the BASIC
Sourced from the World Bank's World Development Indicators (WDI) 2014.

2.4.5.6 Dirty exports and imports

Following Cole (2004), we evaluate the environmental impact of trade flows in pollution-intensive goods by adding to the EKC model two additional variables. The first variable is the ratio of "dirty" imports from developed countries to total imports, the second the ratio of "dirty" exports to developed countries to total exports. A group of 29 OECD member countries are selected as the proxy for developed countries, as detailed in table 2.10.[32] Our definition of dirty industries follows Hettige et al. (1994), including the four sectors designated in the ISIC Rev. 2 as "manufacture of wood and wood products", "manufacture of paper and paper products, manufacture of chemicals and chemical products", "manufacture of non-metallic mineral products", and "basic metal industries". Our dirty exports and imports data are sourced from the World Bank's "Trade, Protection, and Protection database" (Nicita and Olarreaga, 2006), the same database used by Cole (2004) and Kearsley and Riddel (2010). The descriptive statistics of dirty exports and imports ratios are reported in tables 2.11 and 2.12, and line graphs are shown in figure 2.10.

From 1970s to 2004, dirty exports ratios in all four BASIC countries have shown a generally growing up trend with fluctuations; whereas, dirty imports ratios in all four countries have shown a slowly decreasing trend with fluctuations. Our data reveal that exports of four developing countries are getting dirtier and dirtier, whereas imports of four BASIC countries are becoming cleaner and cleaner over the period 1970s to 2004.

[32] These 29 OECD countries are recognized as developed countries by both the World Bank and International Monetary Fund (IMF). Of the five OECD countries excluded from our calculations, Chile, Estonia, Slovenia and Israel began their membership only in 2010. Turkey is also missing due to data availability.

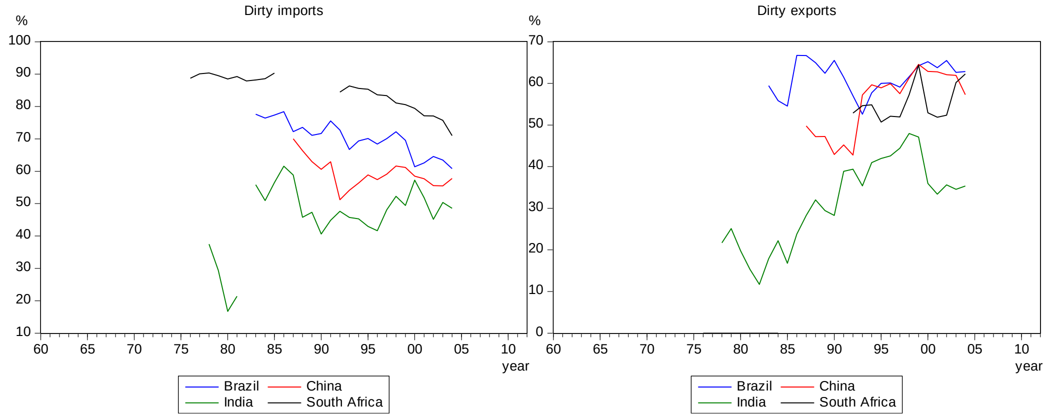

Figure 2.10 Dirty imports and exports ratio in the BASIC
Sourced from the World Bank's Trade, Protection, and Protection database.

Table 2.10 List of 29 OECD countries

Australia	Austria	Belgium	Canada	Czech
Denmark	Finland	France	Germany	Greece
Hungary	Iceland	Ireland	Italy	Japan
South Korea	Luxembourg	Mexico	Netherlands	New Zealand
Norway	Poland	Portugal	Slovak	Spain
Sweden	Switzerland	Turkey	UK	US

Table 2.11 Descriptive statistics of dirty imports and exports ratio in the BASIC

Dirty imports	Brazil	China	India	South Africa
Mean	70.2671	59.3299	45.9075	84.4475
Median	70.5956	58.6928	47.4748	85.6155
Maximum	78.4209	70.0519	61.5868	90.3440
Minimum	60.8152	51.1936	16.7339	71.0240
Std.Dev.	5.2813	4.4798	10.4944	5.4424
Skewness	-0.2647	0.5838	-1.2159	-0.8506
Kurtosis	2.1273	3.3511	4.4448	2.7615
Jarque–Bera	0.9550	1.1149	8.6678	2.8280
Probability	0.6203	0.5727	0.0131	0.2432
Sum	1545.8760	1067.9380	1193.5950	1942.2920
Sum Sq.Dev.	585.7281	341.1708	2753.2950	651.6262
Observations	22*	18**	26***	23****

Dirty imports ratio is in the unit of percentage.
'Std. Dev.' is standard deviation; 'Sum Sq.Dev.' is sum squared deviation.
**Brazil's data are missing for the period 1960-1982 and 2005-2012.*
***China's data are missing for the period 1960-1986 and 2005-2012.*
****India's data are missing for the period 1960-1977, 1982 and 2005-2012.*
****South Africa's data are missing for the period 1960-1975, 1986-1991 and 2005-2012.*
Sourced from the World Bank's Trade, Protection, and Protection database.

Table 2.12 Descriptive statistics of dirty exports ratio in the BASIC

Dirty exports	Brazil	China	India	South Africa
Mean	61.3704	55.6254	31.3293	32.6575
Median	62.0375	58.2350	33.3891	51.8998
Maximum	66.7267	64.5727	47.9662	64.4335
Minimum	52.5834	42.7873	11.7182	0.0000
Std.Dev.	4.0059	7.5236	10.1878	28.0126
Skewness	-0.5479	-0.6144	-0.2016	-0.3244
Kurtosis	2.3950	1.8092	2.0147	1.1711
Jarque–Bera	1.4363	2.1958	1.2752	3.4519
Probability	0.4877	0.3336	0.5286	0.1780
Sum	1350.1490	1001.2580	845.8912	718.4646
Sum Sq.Dev.	336.9922	962.2808	2698.5480	16478.8700
Observations	22*	18**	27***	22****

Dirty exports ratio is in the unit of percentage.
'Std. Dev.' is standard deviation; 'Sum Sq.Dev.' is sum squared deviation.
**Brazil's data are missing for the period 1960-1982 and 2005-2012.*
***China's data are missing for the period 1960-1986 and 2005-2012.*
****India's data are missing for the period 1960-1977 and 2005-2012.*
****South Africa's data are missing for the period 1960-1991 and 2005-2012.*
Sourced from the World Bank's Trade, Protection, and Protection database.

2.5. Estimation Results

In this section, we discuss our estimation results. We begin with our unit root test results. Then we discuss our results from Granger causality test. Thirdly, we discuss our empirical EKC results from panel as well as time series estimators. Lastly, this section is concluded with empirical results for trade effects. All our estimations use the natural logarithms of level series.

2.5.1 Time series properties of the data

To examine the presence of unit roots in our data series, we utilise ADF test and other four unit root test with structural break(s) (as reviewed in section 2.4.1). Our results of unit root test, including conventional ADF test, Perron (1989) test, Zivot and Andrews (1992) test, Lumsdaine and Papell (1997) test, and Lee and Strazicich (2003), are selectively reported in table 2.13[33]. All our unit root tests include both intercept and trend to allow possible structural breaks in both intercept and trend[34], because all our series show a time trend as plotted in the figures (section 2.4.5).

At the significance level of 5%, the ADF test result tells that most of our series cannot reject the null hypothesis of having a unit root, indicating most of our series have

[33] Detail results are available from the authors upon request.
[34] According to Lee and Strazicich (2003), most economic time series can be described adequately as having intercept and trend. We only report results of unit root test allowing both intercept and trend, other results are available from the authors upon request.

a unit root. Whereas, after first difference, the ADF test result shows that all our series cannot reject the null hypothesis of having a unit root, indicating the maximum integration order for our series is 1. However, Perron (1989) test result shows that at 10% level of significance, all our series can reject the null hypothesis of unit root process with one exogenous structural break, indicating our series are stationary with one exogenous structural break[35]. Zivot and Andrews (1992) test result shows that most of all our series, except South Africa's dirty exports and imports, can reject the null hypothesis of having a unit root, indicating most of our series do not have unit roots after addressing one endogenous structural break. The result of Lumsdaine and Papell (1997) test shows that all our series can reject the null of having a unit root at the significance level of 5%, indicating most of the series do not have a unit root after addressing two endogenous structural breaks. Lee and Strazicich (2003) test result also shows that all our series can reject the null hypothesis of having a unit root, indicating most of the series do not have a unit root after addressing two endogenous structural breaks.

Comparing results of 5 unit root tests from accounting no structural break up to addressing two structural breaks, all our series tend to reject the null hypothesis of having a unit root. Our results of 5 unit root tests show that our series are more likely to be stationary with structural breaks rather than having a unit root. This finding supports Perron (1989) argument that most macroeconomics variables are stationary with structural break(s). Basing on this finding, cointegration test may not be necessary since the spurious conclusion that our series have unit roots from the ADF test is caused by the erroneously missing account for any structural break(s) at different break points. Although series with structural break(s) may still be cointegrated, series with different break points are not likely to be cointegrated (Beyer, 2009). Even if our series do have unit roots, the maximum order of integration is 1, since our unit root test results show that all our series are stationary after first difference.

In the testing of possible cointegration between our variables, we opt for the Engle-Granger's (1987) two-step procedure and Pesaran et al.'s (2001) bound test for cointegration using the Autoregressive Distributed Lag (ARDL) model. Our cointegration test result is reported in table 2.14.

[35] Exogenous break point are chosen according to historical economic even in the four countries, such as, the "Real Plan" in 1994 for Brazil; China's leader Deng Xiaoping's a series of political announcement in 1992 symboling a speed-up of market reform, the so called "socialist market economy"; India's economic liberalisation started on 24 July 1991; and South Africa's end of apartheid in 1993.

In our unit root test results, table 2.13 tells that variables in our estimation may have unit roots due to the ADF test result, but table 2.14 shows that there is no evidence that our variables are cointegrated. Thus we utilise FMOLS, CCR and DOLS to deal with potential cointegration problem in our estimation. We acknowledge that since our cointegration test results suggest there is no any cointegration, implementing FMOLS, CCR and DOLS may not be necessary. We still carry out FMOLS, CCR and DOLS for comparison propose to show what misleading results will be found, if we erroneously believe there is cointegration in our regressions.

However, the ADF test result indicates our variables may have unit roots, but results of unit root test with structural break(s) suggest that our variables are actually stationary with structural break(s). As reviewed in section 2.2 and 2.4.5, our variables are likely to be influenced by economic histories in these four developing countries, and moreover all our four developing countries have experienced structural changes in their economies over the period 1960-2012, so we think our variables are more likely to be stationary with structural break(s) rather than nonstationary with unit roots. Furthermore, table 2.14 shows that there is no any evidence that our variables are cointegrated.

Table 2.13: Unit root test results

****, ** and * denotes significance levels of 1%, 5% and 10% respectively.*
t-value is reported in the table and number of lags is reported in the square brackets ( ).
Maximum lag length is 8 and the optimal lag length is determined by Schwarz Information Criteria (SIC) for ADF and Zivot and Andrews (1992) test, but general-to-specific approach for Perron (1989), Lumsdaine and Papell (1994), and Lee and Strazicich (2003) test. Openness: trade openness.

Table 2.13.1 ADF test: level series

	Brazil	China	India	South Africa
GDP	-1.5214 (1)	-1.4318 (1)	-0.1084 (0)	-2.6142 (1)
CO_2	-1.9590 (1)	-3.4254* (1)	-2.0956 (0)	-1.4854 (0)
SO_2	-0.6564 (1)	-3.6623** (0)	-1.6134 (0)	-2.3117 (0)
Trade openness	-4.2579*** (0)	-2.6780* (0)	-2.3232* (0)	-2.2988* (0)
Man. Share	-2.0950** (1)	-5.9306*** (1)	-2.0087* (0)	0.4024 (0)
Man. Exports	-2.6714* (1)	-1.8179 (0)	-2.4661* (1)	-1.5630 (0)
Man. Imports	-1.0487 (1)	-6.1765*** (1)	-1.7426 (0)	-2.3016* (0)
Dirty exports	-3.9787** (0)	-1.8668 (0)	-1.2482 (0)	-3.7975** (1)
Dirty imports	-4.0424** (1)	-2.9408* (1)	-1.0799 (0)	-0.4318 (0)

Table 2.13: Unit root test results (continues)

Table 2.13.2 ADF test: 1st difference series

	Brazil	China	India	South Africa
GDP	-3.2288***(2)	-4.4418***(0)	-5.6539***(0)	-3.3326***(0)
CO_2	-3.3796***(0)	-5.3585***(0)	-6.9706***(0)	-5.0570***(0)
SO_2	-3.2342***(0)	-4.3391***(0)	-5.0909***(0)	-5.2716***(0)
Trade openness	-5.0694***(0)	-3.7148***(0)	-6.2576***(1)	-4.2496***(0)
Man. Share	-7.3183*** (0)	-5.9318*** (0)	-6.3933*** (0)	-4.9945*** (0)
Man. Exports	-6.0874*** (0)	-4.7438*** (0)	-7.5419*** (0)	-8.5774*** (0)
Man. Imports	-5.8288*** (0)	-3.5665*** (0)	-9.6837*** (0)	-5.0779*** (0)
Dirty exports	-2.5627** (0)	-4.3119*** (0)	-2.1832** (0)	-3.3196*** (0)
Dirty imports	-4.8376*** (0)	-4.6762*** (0)	-4.9379*** (0)	-3.7511*** (0)

Table 2.13.3 Perron (1989) test: level series

	Brazil	China	India	South Africa
GDP	-4.4863** (0)	-4.3463** (0)	-5.3118*** (0)	-4.4255** (0)
CO_2	-4.3111** (2)	-3.8457** (2)	-3.7082** (3)	-4.2997** (2)
SO_2	-6.5303*** (1)	-6.2187*** (1)	-6.1670*** (1)	-7.5986*** (0)
Trade openness	-4.8347** (2)	-4.5666** (2)	-4.4317** (2)	-4.5419** (2)
Man. Share	-5.9583*** (2)	-6.0145*** (1)	-5.6421*** (1)	-4.8561** (1)
Man. Exports	-3.8954** (1)	-4.1257** (0)	-3.5614** (1)	-3.1856* (1)
Man. Imports	-4.5871** (0)	-5.1242*** (1)	-3.4861** (1)	-4.0125** (0)
Dirty exports	-3.2158* (1)	-3.4521* (0)	-3.8465** (1)	-3.2121* (0)
Dirty imports	-3.5684* (1)	- 4.0154** (0)	-3.2259* (0)	-3.5871** (0)

Table 2.13.4 Zivot and Andrews (1992) test: level series

	Brazil	China	India	South Africa
GDP	-4.8674*** (2) <1981>	-4.5728*** (2) <1976>	-3.3563** (2) <1979>	-3.4636** (1) <1985>
CO_2	-5.3586*** (2) <1980>	-4.5494*** (1) <2002>	-3.7014** (0) <1977>	-3.1667** (0) <1983>
SO_2	-3.2527** (1) <1979>	-4.4482** (1) <1978>	-3.7491** (2) <1982>	-3.7422** (0) <1972>
Trade openness	-4.1827** (1) <1986>	-6.0919*** (1) <1983>	-3.3678** (0) <1985>	-3.9074** (0) <1989>
Man. Share	-3.1378** (2) <1978>	-2.9295** (2) <1985>	-3.4267** (0) <1974>	-1.3318** (2) <1986>
Man. Exports	-2.2182** (2) <1976>	-5.6933*** (1) <1997>	-5.0128*** (2) <1985>	-4.2600*** (2) <1984>
Man. Imports	-3.5704*** (2) <1992>	-2.9562** (1) <1996>	-3.5311** (1) <1987>	-3.4743** (2) (1985)
Dirty exports	-2.5147** (1) <1993>	-3.1245** (0) <1992>	-2.3147** (0) <1988>	-1.2451 (0) <1999>
Dirty imports	-3.1475** (0) <1994>	-3.5478** (0) <1992>	-2.3547** (0) <1990>	-1.4584 (0) <1985>

Table 2.13: Unit root test results (continues)

Table 2.13.5 Lumsdaine and Papell (1997) test

	Brazil	China	India	South Africa
GDP	-7.5460** (4)	-15.8110*** (3)	-25.0582*** (3)	-10.9929*** (4)
CO_2	-8.2155*** (2)	-12.4210*** (1)	-7.4781** (1)	-15.6792*** (3)
SO_2	-10.2966*** (3)	-8.3617*** (4)	-11.4848*** (2)	-14.2523*** (3)
Trade openness	-7.9551*** (3)	-6.9150** (2)	-8.6017*** (3)	-7.3043** (3)
Man. Share	-8.1479*** (2)	-7.4581** (3)	-6.8894** (2)	-7.5567** (2)
Man. Exports	-6.9841** (3)	-8.5441*** (3)	-7.5147** (1)	-6.8453** (1)
Man. Imports	-7.2411** (4)	-7.6844** (4)	-7.3421** (3)	-7.2556** (2)
Dirty exports	-6.5774** (2)	-7.9848*** (1)	-6.8959** (1)	-6.8554**(0)
Dirty imports	-6.9954** (1)	-6.8475** (0)	-7.0144** (2)	-6.4411** (0)

2.15.6 Lee and Strazicich (2003) test

	Brazil	China	India	South Africa
GDP	-21.5016*** (2)	-15.3376*** (4)	-19.4359*** (4)	-18.6509*** (3)
CO_2	-13.7417*** (3)	-7.8456** (2)	-6.4605** (2)	-6.9395** (3)
SO_2	-23.0959*** (4)	-22.9647*** (3)	-9.3587*** (4)	-11.2848*** (4)
Trade openness	-7.0133** (2)	-6.4427** (4)	-6.8490** (3)	-7.8542** (4)
Man. Share	-9.1458*** (3)	-8.0132** (4)	-7.4411** (2)	-8.6552*** (3)
Man. Exports	-7.0853** (2)	-7.5443** (3)	-6.9332** (1)	-7.5587** (1)
Man. Imports	-6.6855** (1)	-6.9991** (2)	-7.0113** (2)	-6.9933** (0)
Dirty exports	-7.3665** (2)	-6.8814** (1)	-6.5335** (0)	-7.0002**(1)
Dirty imports	-7.0117** (1)	-7.0022** (0)	-6.9123** (0)	-6.6148** (0)

Table 2.14: Cointegration test results

****, ** and * denotes significance levels of 1%, 5% and 10% respectively.*

For unit root test result, t-value is reported in the table and number of lags is reported in the square brackets ( ). Maximum lag length is 8 and the optimal lag length is determined by Schwarz Information Criteria (SIC). CKC: the EKC for CO_2 emissions. SKC: the EKC for SO_2 emissions

Table 2.14.1: Engle-Granger's two-step Error Correction Model for cointegration

Step 1: OLS estimation of the EKC

CO_2	Brazil	China	India	South Africa
Constant	-26.7267**	0.4169	-11.7022**	-90.2171
GDP	7.0135***	1.4372***	4.3689***	21.3771*
GDP^2	-0.3611**	-0.0590**	-0.2662***	-1.1524*
GDP^3				
EKC relation	Inverted U	Inverted U	Inverted U	Inverted U

SO_2	Brazil	China	India	South Africa
Constant	-106.5240***	-25.0386**	-35.2443***	-137.2293***
GDP	24.6193***	10.7509**	9.2390***	30.4416***
GDP^2	-1.3913***	-1.4121*	-0.5827***	-1.6362***
GDP^3		0.0632*		
EKC relation	Inverted U	Positive linear	Inverted U	Inverted U

Step 2: Unit root test of the residuals

	Brazil	China	India	South Africa
CKC residuals	-1.7746	-2.7798	-3.3403	-1.3580
SKC residuals	-2.1605	-3.3082	-2.0704	-0.5872

Table 2.14: Cointegration test results (continues)

Step3: Error correction model (Δ represents first difference)

Δ CO_2	Brazil	China	India	South Africa
Constant	0.0008	-0.0244*	0.0330*	0.0081
Δ GDP	1.9750	1.1838*	0.2111	16.3860
Δ GDP^2	-0.0570	-0.0182	-0.0069	-0.8990
Δ GDP^3				
Error Correction	-0.1860	-0.0999	-0.2005	-0.1450
EKC relation	No relation	No relation	No relation	No relation

Δ SO_2	Brazil	China	India	South Africa
Constant	-0.0150**	-0.0293	0.0321*	-0.0035
Δ GDP	6.2069	3.3860	-2.7047	10.6006
Δ GDP^2	-0.3054	-0.3965	0.1766	-0.5560
Δ GDP^3		0.0196		
Error Correction	0.0278	-0.2412	-0.0486	-0.2897
EKC relation	No relation	No relation	No relation	No relation

Table 2.14.2: Autoregressive Distributed Lag (ARDL) approach for cointegration

	Brazil	China	India	South Africa
CO_2	0.6487 (1)	2.1535 (1)	1.1419 (1)	1.6414 (1)
SO_2	3.1415 (2)	2.3853 (1)	2.4809 (1)	1.2411 (1)

F statistics is reported, and "NA" represents no value is available.

2.5.2 Granger causality test

Following the Toda and Yamamoto (1995) approach to Granger causality test for possibly integrated and cointegrated series, we first set up VAR models with the natural logarithms of level series and decide the optimal lag length (p). As shown in table 2.15, although the five information criteria do not always agree,[36] they nonetheless all select either one lag or two lags as the optimal lag order for the eight VAR models. However, the information criteria cannot ensure the residuals of the selected VAR are free of serial correlation. To ensure the residuals are free of serial correlation problem, we introduce more lags to our VAR models as suggested by Toda and Yamamoto (1995) until the residuals are not serial correlated. As reported in table 2.16, results of VAR residual serial correlation LM test[37] suggest the optimal lag numbers of our VAR models are as reported in the brackets for each county respectively. These numbers of lags can ensure our VAR models being free of the serial correlation problem, whereas

[36] Details about these five information criteria can be found in Lütkepohl (2005).
[37] Details of the LM test can be found in Johansen (1995).

any lag length less than the optimal one cannot[38]. Figures 2.11 and 2.12 show the graphs of the inverse roots of the characteristic AR polynomials for the eight VARs with the lag order of each VAR chosen by the LM test. As there are no roots on or outside the unit circle, all eight VAR systems appear to be stable.[39]

The unit root test results reported in section 2.5.1 indicate that the maximum order of integration of all the series entering the VARs is one ($d = 1$). We, therefore, re-estimate each of the eight VARs with one extra lag included. In other words, the lag order of each VAR, m, is given by $m = p + d$, where p is the optimal lag length chosen by the LM test and $d = 1$. Granger causality tests are then performed on the estimated $VAR(m)$'s, and the results are reported in table 2.17.

The Granger causality test results in table 2.17 show evidence of unidirectional causality from GDP to CO_2 and SO_2 emissions in all four BASIC countries, but this piece of evidence is only significant at 10% level indicating the Granger causality may not be statistically significant. There is, however no evidence of any causality between trade openness and GDP, or between trade openness and CO_2 or SO_2 emissions. These results are in broad agreement with those reported in a number of recent studies such as Chang (2010), Fodha and Zaghdoud (2010), and Hatzigeorgiou et al. (2011), among others. This result suggests we may need to include values of lagged GDP our EKC estimations, however including lag values of GDP does not significantly change our estimation results. This is because our Granger causality test results only provide weak evidence of unidirectional causality from GDP to CO_2 and SO_2 emissions.

Hence, on the empirical level, our Granger causality test results lend some support to the popular belief that the increase in material wellbeing achieved in the developing world over the last half century has come to some extent at the expense of the natural environment. On the conceptual level, no evidence is found against the inverted U-shaped relationship between income and pollution as postulated by the EKC hypothesis. Neither is there any evidence in support of the PHH or FEH since trade openness turns out to be uncorrelated with pollution emissions. However, since Granger causality emphasise on the causality running from past information, it is predictive causality but not structural causality. Also as reviewed in the data section 2.4.5, we should be caution with our finding about the relationship between CO_2 emissions, SO_2 emissions and

[38] Following existing literature, we apply a recursive serial correlation test approach, which means we run our serial correlation test from lag length of 1 first, and then adding 1 more lag for each test until our optimal lag length. We find any lag length less than the optimal lead our VAR having serial correlation problem.

[39] For detailed discussion of stable VAR, please see Lütkepohl (2005).

income, since CO_2 and SO_2 emissions may not be representative of total pollution emissions.

We do not consider non-linearity problem is because as shown in the data section most of our series are linear. Even we assume that we are facing non-linearity problems, the normal way to deal with non-linear problem is to “divide and rule”, thus we will not have enough observations to carry out non-linear regressions (Tong, 1983). We either do not consider any omitted variable problem, since our theories: EKC, PHH and FEH, suggest relationship between income, trade and pollution only with no any other factors.

Table 2.15 Optimal lag length

** indicates lag order selected by the criterion*
LR: sequential modified LR test statistic (each test at 5% level)
FPE: Final prediction error
AIC: Akaike information criterion
SC: Schwarz information criterion
HQ: Hannan-Quinn information criterion

Table 2.15.1: VAR of CO_2 emissions per capita, GDP per capita and trade openness
Brazil

Lag	LR	FPE	AIC	SC	HQ
0	NA	2.13E-06	-4.544582	-4.411266	-4.498561
1	157.1878*	2.25e-08*	-9.100869*	-8.567607*	-8.916787*
2	12.04418	2.48E-08	-9.016732	-8.083524	-8.694589
3	7.47379	3.17E-08	-8.801398	-7.468243	-8.341193

China

Lag	LR	FPE	AIC	SC	HQ
0	NA	0.0000868	-0.838764	-0.705448	-0.792743
1	251.8921	4.31E-08	-8.450029	-7.916767*	-8.265947*
2	17.53454*	3.90e-08*	-8.561977*	-7.628768	-8.239833
3	7.37114	5.02E-08	-8.342536	-7.009381	-7.882331

India

Lag	LR	FPE	AIC	SC	HQ
0	NA	6.83E-08	-7.986828	-7.720197	-7.894787
1	106.9001	3.25E-09	-11.03588	-10.36930*	-10.80578
2	19.35227*	2.71e-09*	-11.23835*	-10.17182	-10.87018*
3	9.945948	3.12E-09	-11.13847	-9.672004	-10.63225

South Africa

Lag	LR	FPE	AIC	SC	HQ
0	NA	9.25E-07	-5.379548	-5.246233	-5.333528
1	171.2428*	6.19e-09*	-10.38922*	-9.855963*	-10.20514*
2	6.958923	8.19E-09	-10.12347	-9.190263	-9.801328
3	9.409533	9.71E-09	-9.985568	-8.652412	-9.525362

Table 2.15: Optimal lag length (continues)

Table 2.15.2: VAR of SO_2 emissions, GDP and trade openness

Brazil

Lag	LR	FPE	AIC	SC	HQ
0	NA	1.17E-06	-5.142584	-5.005171	-5.097035
1	132.8173	1.80E-08	-9.323557	-8.773906*	-9.141363
2	19.54100*	1.47e-08*	-9.542697*	-8.580808	-9.223858*
3	5.535842	2.10E-08	-9.231826	-7.857699	-8.776342

China

Lag	LR	FPE	AIC	SC	HQ
0	NA	5.47E-05	-1.299459	-1.162046	-1.253911
1	208.3700*	5.65e-08*	-8.178746*	-7.629096*	-7.996553*
2	8.358009	7.23E-08	-7.950567	-6.988678	-7.631728
3	13.81022	7.07E-08	-8.02E+00	-6.641677	-7.56032

India

Lag	LR	FPE	AIC	SC	HQ
0	NA	6.21E-06	-3.476474	-3.339061	-3.430925
1	240.7177*	2.02e-09*	-11.51103*	-10.96138*	-11.32884*
2	9.225913	2.49E-09	-11.31757	-10.35568	-10.99873
3	9.166526	3.01E-09	-11.17173	-9.797603	-10.71625

South Africa

Lag	LR	FPE	AIC	SC	HQ
0	NA	4.02E-07	-6.212867	-6.075455	-6.167319
1	119.9721*	9.76E-09	-9.935086	-9.385435*	-9.752892*
2	15.45852	9.40e-09*	-9.990927*	-9.029038	-9.672088
3	8.199175	1.19E-08	-9.801117	-8.426989	-9.345632

Table 2.16 Autocorrelation LM test

Probability of LM statistics is reported in the table for each lag.
Lag length of VAR is in the brackets ( ) after the country name.

Table 2.16.1 VAR of CO_2 emissions, GDP, and trade openness

Lags	Brazil (2)	China (2)	India (1)	South Africa (2)
1	0.5257	0.6472	0.3517	0.1336
2	0.9033	0.5884	0.3198	0.2462
3	0.2242	0.6712	0.6585	0.4809
4	0.1079	0.1107	0.8402	0.7314
5	0.7182	0.2114	0.2959	0.0650
6	0.1555	0.6285	0.8962	0.9924
7	0.5291	0.9535	0.4639	0.9092
8	0.9808	0.6135	0.6402	0.3383
9	0.1155	0.0507	0.9966	0.0901
10	0.5341	0.9860	0.8516	0.0826
11	0.9895	0.5434	0.9406	0.8030
12	0.6811	0.6422	0.4548	0.4473

Table 2.16.2 VAR of SO_2 emissions, GDP, and trade openness

Lags	Brazil (2)	China (2)	India (1)	South Africa (2)
1	0.6966	0.2832	0.3602	0.8018
2	0.6733	0.2977	0.3792	0.3535
3	0.4170	0.8453	0.2074	0.0543
4	0.5882	0.4089	0.3110	0.7643
5	0.0966	0.1991	0.7413	0.1894
6	0.6623	0.4817	0.3132	0.3029
7	0.8297	0.6328	0.9315	0.8070
8	0.8574	0.4298	0.1560	0.2934
9	0.3996	0.2022	0.9568	0.9587
10	0.6827	0.9546	0.1259	0.3048
11	0.6205	0.5315	0.4178	0.9888
12	0.7169	0.3434	0.0669	0.9501

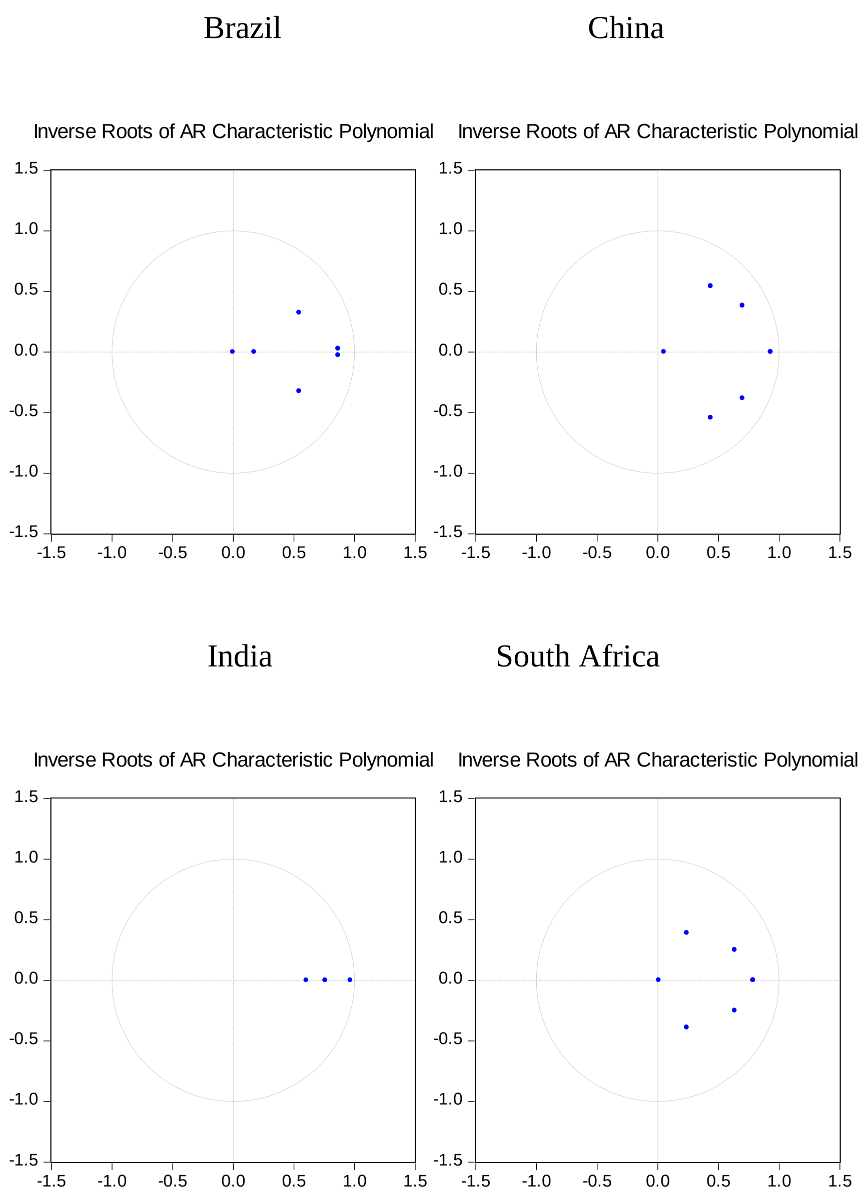

Figure 2.11: Inverse roots of characteristic AR polynomial for VAR with CO_2 emissions

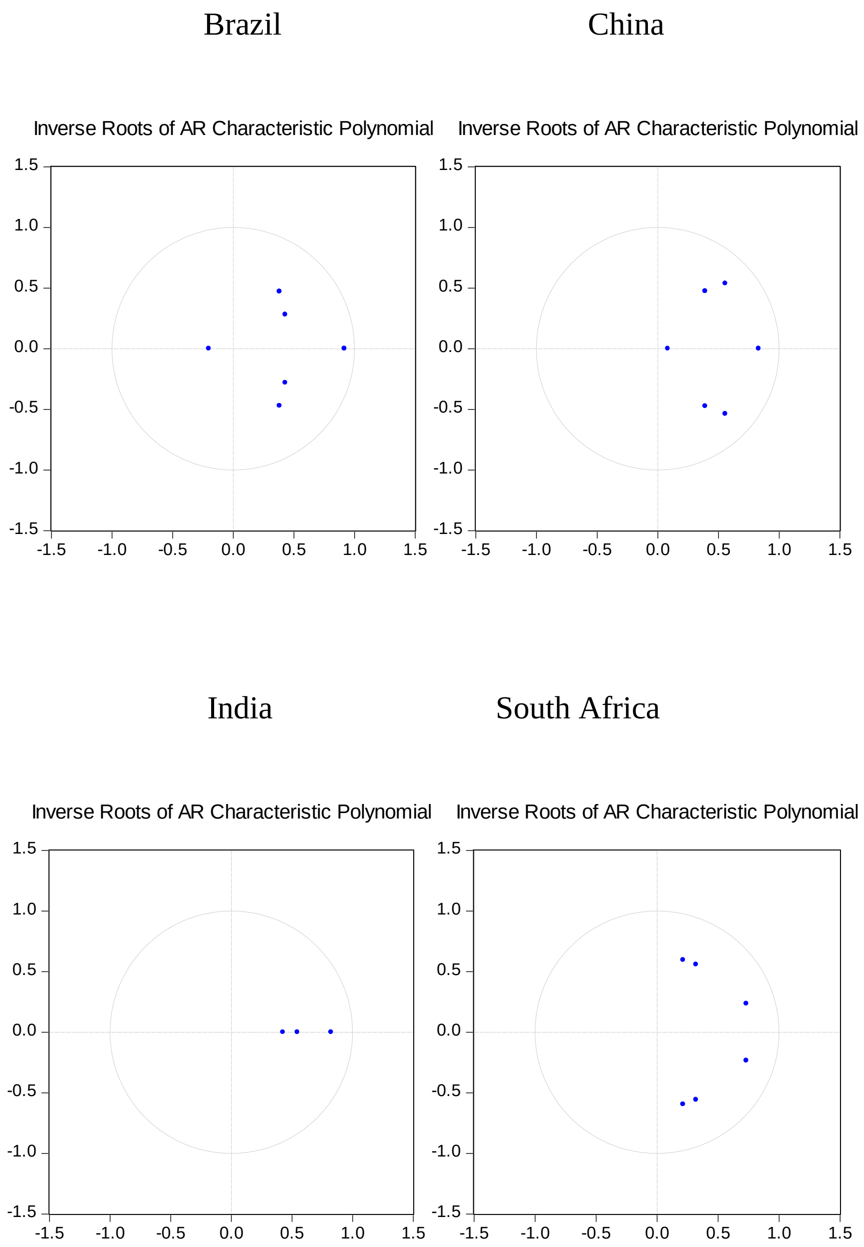

Figure 2.12: Inverse roots of characteristic AR polynomial for VAR with SO_2 emissions

Table 2.17 Granger causality test results

P-values are reported.
Lag length of VAR is in the brackets ( ) after country name.
****, ** and * denote significance levels of 1%, 5% and 10% respectively.*
CO_2: CO_2 emissions per capita; and SO_2: SO_2 emissions per capita.
Open.: Trade openness ratio.

Table 2.17.1: CO_2 emissions, GDP and trade openness

CO_2 emissions	Brazil (2)	China (2)	India (1)	South Africa (2)
GDP→ CO_2	0.0543*	0.0686*	0.0573*	0.0874*
GDP → Open	0.2109	0.1110	0.1467	0.1238
CO_2 → GDP	0.2956	0.7313	0.5130	0.6178
CO_2 → Open	0.9880	0.2255	0.3401	0.9279
Open. → CO_2	0.8591	0.5157	0.9029	0.9709
Open. → GDP	0.3743	0.8790	0.2425	0.1136

Table 2.17.2: SO_2 emissions, GDP and trade openness

SO2 emissions	Brazil (2)	China (2)	India (1)	South Africa (2)
GDP → SO_2	0.0824*	0.0418**	00220**	0.0738*
GDP → Open	0.3442	0.7499	0.9123	0.1007
SO_2 → GDP	0.3666	0.8415	0.6461	0.1331
SO_2 → Open	0.6266	0.3083	0.1346	0.7885
Open → SO_2	0.4029	0.4682	0.8561	0.3235
Open → GDP	0.1840	0.7765	0.6695	0.4621

2.5.3 Estimation result of the EKC

In this section, we discuss our estimation result. Our analysis focuses on the individual country estimation result but not the BASIC countries as a group. As aforementioned (see section 2.3) in most previous studies, the EKC equation is estimated with panel data using fixed- and/or random-effect estimators. These studies make the implicitly assumption that all countries included in the sample have the same income turning point and same income elasticity of pollution. However, as we have argued earlier (see section 2.2) that, given the diverse experiences of the four BASIC countries in the last half century, this homogeneity assumption would be too restrictive. In our panel estimation, we investigate whether there is any support for the homogeneity assumption by applying three panel estimation techniques which vary in the commonality restrictions imposed on the parameters. At one end of the spectrum, the mean group (MG) estimator allows heterogeneity in all parameters of both the long-run and short-run models. At the other end, the dynamic fixed-effect estimator assumes heterogeneity in the constant term in the short-run model only. Sitting in between the two extremes is the pooled mean group (PMG) estimator, which assumes a common long-run relationship between all cross sections but allows heterogeneity in all parameters in the short-run model (Pesaran et al., 1999, and Blackburne III and Frank, 2007). Our panel estimation results show no statistically significant coefficients, even in the case we consider structural break(s). These panel estimation results are available from the author upon request. Our finding suggests that treating four developing countries as a group may not be proper, supporting the argument put forward by de Bruyn (1998), Stern et al,. (1996) and Dasgupta et al. (2002) among others, that a common EKC for the whole world may not be appropriate, and each country is likely to have individual EKC shape. Therefore, empirical EKC studies should be carry out for each individual country rather than pooling countries together, so we carry out empirical study for each of the four BASIC countries in the coming sections.

We consider three specifications of the EKC equation – the cubic, quadratic and linear forms – are fitted to the data of the four countries individually. Before turning to model estimation, we first plot per capita CO_2 and SO_2 emissions against per capita GDP for each of the four BASIC countries in figures 2.13 and 2.14. Figure 2.13 shows the relationship between per capita CO_2 emissions and per capita GDP is likely to be linear in these countries. At least there is no clear tendency that further rise in per capita GDP will reduce per capita CO_2 emissions. However, in the case of SO_2 emissions, it can be seen that there may be an inverted U shape relationship between SO_2 emissions and per capita GDP in Brazil, India and South Africa (figure 2.14).

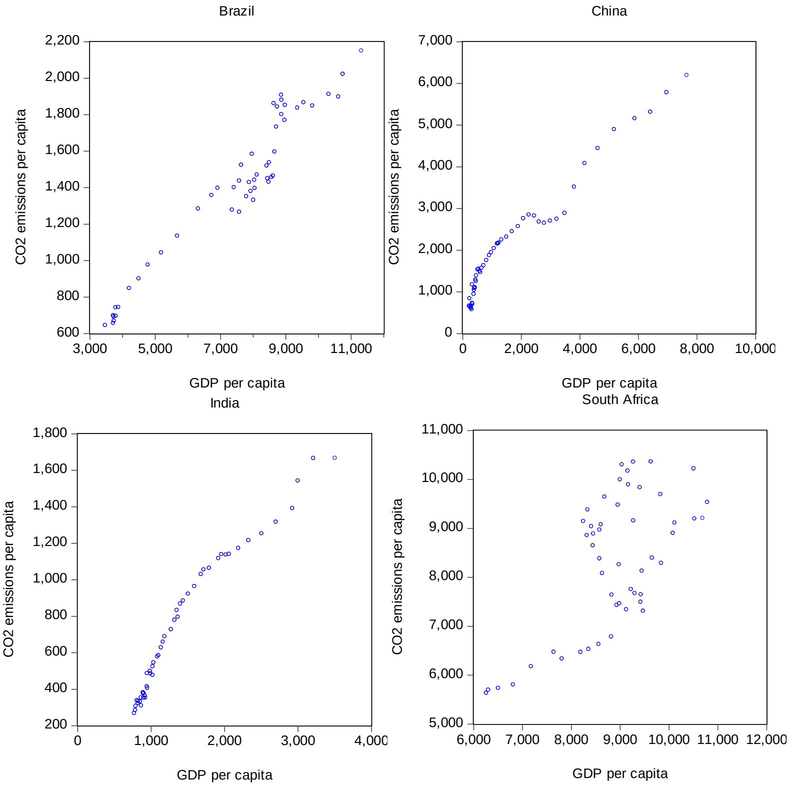

Figure 2.13: Per capita CO2 emissions (in kilos) against per capita GDP (in \$) (1960–2012)

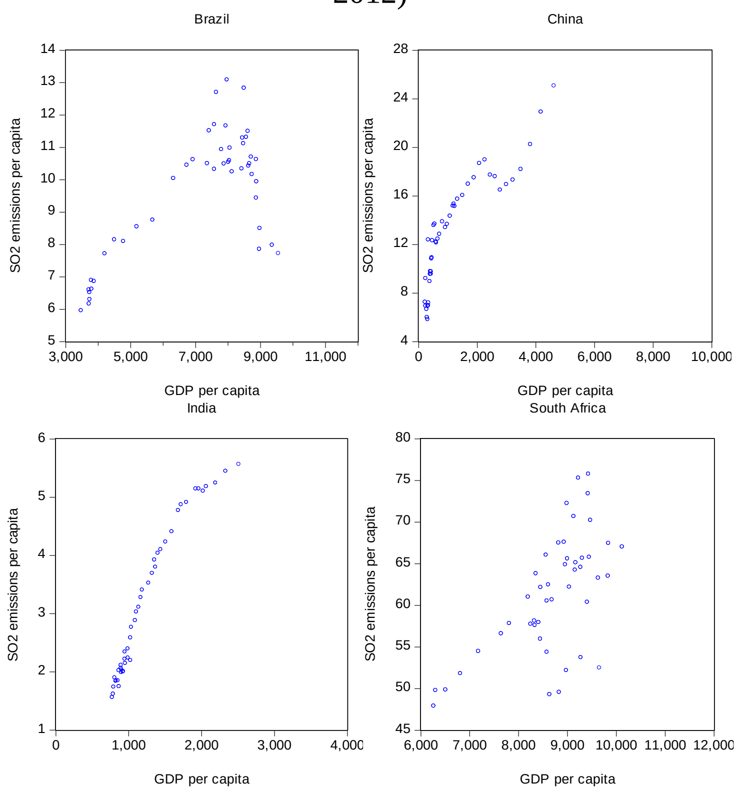

Figure 2.14: Per capita SO2 emissions (in kilos) against per capita GDP (in \$) (1960–2012)

A common criticism of the early EKC studies is that they fail to account for possible presence of unit root and cointegration among the data series. As the tests in section 2.5.1 do not provide a clear-cut answer as to whether the series are stationary or integrated of order one, we employ three single equation cointegration estimators that are robust to I(0), I(1) and cointegrated series: Fully Modified Ordinary Least Square (FMOLS) estimator, Canonical Cointegrating Regression (CCR) and Dynamic Ordinary Least Square (DOLS) estimator. Following the general to specific approach used in previous EKC studies (see literature in section 2.3), we start with the cubic form of the EKC model. If the cubic form estimation does not offer statistically significant results, we drop the cubed term of GDP per capita from the regression equation and move on to the quadratic form of the EKC. If the quadratic model still does not perform satisfactorily, the linear form is then chosen. The estimation results of the models selected by this procedure are summarised in table 2.18. Moreover, since the cubic, quadratic and linear forms of EKC equation are nested models, we can employ the LR test to help us to choose between them. Our LR test results are reported in table 2.19. Our LR test results support our selection of EKC forms for the BASIC countries.

As shown in table 2.18, an inverted U shape relationship between per capita CO_2 emissions and per capita GDP is found in all four countries. In the case of SO_2 emissions, Brazil, India and South Africa seem to have an inverted U shape EKC, but China has a monotonic positive cubic SKC. These results are consistent across the four different estimators – OLS, FMOLS, CCR and DOLS.

It is worth noting that for Brazil, China and South Africa the estimated turning points of the EKC for CO_2 emissions are well above their current income levels. For India, the estimated turning points are around its per capita GDP level in 2012 ($3,752.62). By comparison, the estimated income turning points for the SO_2 EKC are much lower than those for the CO_2 EKC. In fact, the estimates suggest that, with the exception of China, the other three countries have already passed the turning point.

The finding in table 2.18 of an inverted U-shaped EKC for per capita CO_2 emissions accords well with the results in a number of previous studies, such as Shafik and Bandyopadhyay (1992), Holtz-Eakin and Selden (1995), Cole et al. (1997), Agras and Chapman (1999), Galeotti and Lanza (1999), Sachs et al. (1999), Cavlovic et al. (2000), Heil and Selden (2001) and Piaggio and Padilla (2012). However, the turning point ranges from our estimation are generally higher than the current income level, except India, indicating that the relationship between pollution and income in these four countries may follow an inverted U shape, but Brazil, China, and South Africa are still quite some distance away from reaching the threshold level of income.

The results regarding SO_2 emissions in table 2.18 are also in line with those obtained in previous studies. Like us, De Bruyn et al. (1998) and Stern and Common (2001) find that China's SO_2 emissions per capita increases monotonically with income. Similar to our finding an inverted U-shaped EKC for SO_2 emissions in Brazil, India and South Africa, Ansuategi (2000), Cole (2000), Cole et al. (1997), Gallet et al. (1999), Hill and Magnani (2002), List and Gallet (1999), List and Gerking (2000), Millimet et al. (2000), Panayotou (1995), Perrings and Ansuategi (2000), Selden and Song (1994), Stern and Common (2001), among others, all confirm such a relationship for various countries. However, the relatively low and inside sample turning points in these three countries are bit surprising. Previous studies often find out of sample turning points for the SO_2 EKC, such as \$10,500 (Gallet et al., 1999), \$7,400 – \$12,700 (Hill and Magnani, 2002), \$22,600 (List and Gallet, 1999), \$26,100 (List and Gerking, 2000), \$8,000 (Millimet et al., 2000), \$9,600 (Perrings and Ansuategi, 2000), \$8,700 – \$10,700 (Selden and Song, 1994), and \$9,200 (Stern and Common, 2001) among others. And noticeably, all SO_2 EKC turning points estimated by previous studies are well above our estimation. Our results suggest that some BASIC countries may actually perform better than expected in the measure of CO_2 and SO_2 emissions, and may have already passed the turning points for some pollutants.

Our results of the shapes of EKC in BASIC countries show not come with surprise, since it is widely argued that though four BASIC countries are all emerging economies with fast economic growth rates, they actually have different growth paths. For instance, China's fast growth is significantly contributed by her performance in manufacturing industries, whereas, Brazil, India and South Africa's growth is mainly driven by their service industries.

Table 2.18 EKC estimation results for individual countries

CKC: the EKC for CO_2 emissions
SKC: the EKC for SO_2 emissions
Turning point income is in the unit of $, constant 2000 international dollar.
, **, *, represent significance level of 10%, 5% and 1% respectively.*
Number of leads and lags of DOLS are selected by Schwarz Information Criterion (SIC) and reported in [] in the form of [leads, lags].

Table 2.18.1: CKC

Brazil

	OLS	FMOLS	CCR	DOLS [0, 0]
Constant	-26.7267**	-34.2881*	-33.2763*	-30.0468*
GDP	7.0135**	8.8128**	8.5769*	7.7983**
GDP squared	-0.3611**	-0.4684*	-0.4546*	-0.4078*
GDP cubed				
EKC relation	Inverted U	Inverted U	Inverted U	Inverted U
Turning point	16,503.0222	12,177.2053	12,495.0611	14,196.7663

China

	OLS	FMOLS	CCR	DOLS [1, 0]
Constant	0.4169	-0.2511	-0.3261	-0.2848
GDP	1.4372***	1.6258***	1.6498**	1.6900***
GDP squared	-0.0590**	-0.0721*	-0.0740*	-0.0823*
GDP cubed				
EKC relation	Inverted U	Inverted U	Inverted U	Inverted U
Turning point	192,957.1101	78,795.5918	69,401.3356	28,936.3804

India

	OLS	FMOLS	CCR	DOLS [0, 0]
Constant	-11.7022**	-14.0510	-13.2948	-12.5941
GDP	4.3689***	4.9551**	4.7491*	4.5755*
GDP squared	-0.2662***	-0.3011**	-0.2873*	-0.2771*
GDP cubed				
EKC relation	Inverted U	Inverted U	Inverted U	Inverted U
Turning point	3,662.1358	3,741.4652	3,891.2357	3,854.9275

South Africa

	OLS	FMOLS	CCR	DOLS [0, 0]
Constant	-90.2171*	-56.6120	-72.6201	-36.7844
GDP	21.3771*	13.5445*	17.0334*	9.3220*
GDP squared	-1.1524*	-0.6953*	-0.8853*	-0.4708*
GDP cubed				
EKC relation	Inverted U	Inverted U	Inverted U	Inverted U
Turning point	10,665.2779	16,985.4150	15,057.6252	19,944.0070

Table 2.18: Individual country estimation results (continues)
CKC: the EKC for CO_2 emissions
SKC: the EKC for SO_2 emissions
Turning point income is in the unit of $, constant 2000 international dollar.
, **, *, represent significance level of 10%, 5% and 1% respectively.*
Number of leads and lags of DOLS are selected by Schwarz Information Criterion (SIC) and reported in [ ] with the form of [leads, lags].

Table 2.18.2: SKC

Brazil

	OLS	FMOLS	CCR	DOLS [2, 1]
Constant	-106.5240***	-137.8021***	-140.0895***	-176.1094***
GDP	24.6193***	31.8834***	32.4225***	40.7933***
GDP squared	-1.3913***	-1.8121***	-1.8438***	-2.3286***
GDP cubed				
EKC relation	Inverted U	Inverted U	Inverted U	Inverted U
Turning point	6,959.3804	6,617.2994	6,584.9209	6,368.8108

China

	OLS	FMOLS	CCR	DOLS [1, 2]
Constant	-25.0386**	-40.5461**	-43.6657**	-36.7000**
GDP	10.7509**	17.5412**	19.0474**	15.9484**
GDP squared	-1.4121*	-2.3949**	-2.6349**	-2.1732*
GDP cubed	0.0632*	0.1102**	0.1228**	0.0996*
EKC relation	Positive linear	Positive linear	Positive linear	Positive linear
Turning point	NA	NA	NA	NA

India

	OLS	FMOLS	CCR	DOLS [2, 0]
Constant	-49.7253***	-52.8195***	-53.3229***	-49.0006***
GDP	13.0248***	13.8796***	14.0271***	12.7959***
GDP squared	-0.8244***	-0.8833***	-0.8941***	-0.8070***
GDP cubed				
EKC relation	Inverted U	Inverted U	Inverted U	Inverted U
Turning point	2,696.6800	2,582.7227	2,551.3035	2,774.1652

South Africa

	OLS	FMOLS	CCR	DOLS [0, 0]
Constant	-137.2293***	-176.1479**	-193.8851***	-148.7523**
GDP	30.4416***	39.1466**	43.0888***	33.2079**
GDP squared	-1.6362***	-2.1225**	-2.3414***	-1.8005**
GDP cubed				
EKC relation	Inverted U	Inverted U	Inverted U	Inverted U
Turning point	10,967.3085	10,115.5755	9,911.8745	10,114.3660

Table 2.19 LR test for three forms of EKC

Null hypothesis of Cubic vs Quadratic: the cubic term is insignificant
Null hypothesis of Quadratic vs Linear: the quadratic term is insignificant
CKC: the EKC for CO_2 emissions
SKC: the EKC for SO_2 emissions
, **, *, represent significance level of 10%, 5% and 1% respectively.*

CKC	Cubic vs Quadratic	Quadratic vs Linear
Brazil	0.0002	6.7028***
China	3.0498	6.3217**
India	1.1540	9.9063***
South Africa	0.3955	3.1907*

SKC	Cubic vs Quadratic	Quadratic vs Linear
Brazil	0.3939	46.0699***
China	3.1092*	14.1470***
India	1.1433	38.3727***
South Africa	n.a.	7.3738***

2.5.4 Time series result of trade effects

In this section, we investigate trade effects on CO_2 and SO_2 emissions, employing specifications proposed by Grossman and Krueger (1991), Suri and Chapman (1998), and Cole (2004). According to our unit root test results in section 2.5.1, we cannot be sure whether our variables are stationary or having a unit root. Therefore, we employ the DOLS model for our estimation, since the DOLS model is applicable regardless of whether our variables are I(1) or I(0). Our estimation results are reported in table 2.20 and 2.21. We only provide selective results, since estimation results with high order polynomial income terms show massive insignificant coefficients. This approach is also supported by our LR test results (table 2.19).

Table 2.20 and 2.21 show that our results provide no evidence that international trade significantly affects CO_2 and SO_2 emissions. Coefficients of trade openness in all three specifications (Grossman and Krueger, 1991, Suri and Chapman, 1998, and Cole, 2004) are insignificant, so as coefficients of manufacturing exports, manufacturing imports, dirty exports and dirty imports. Our results are not surprising since as reviewed in the existing theoretical studies, international trade may have positive as well as negative effects on pollution. Trade increases pollution through trade-induced scale and composition effects, for example trade increases the total GDP and stimulates dirty production; but trade reduces pollution through trade-induced technique and composition effects, for instance trade brings in more energy efficient production techniques and promotes clean production. If positive effects cancel out negative effects, international trade in overall will have an insignificant effect on pollution. Our results suggest that international trade should not be blamed for CO_2 and SO_2 emissions in four BASIC countries.

It may be also worth noting that the shape of EKC for CO_2 and SO_2 emissions in four BASIC countries does not change. Comparing Table 2.20 and 2.21 with table 2.18, it can be seen clearly that the shape of EKC remains the same, but just the turning points are slightly different. Our finding shows the CO_2 and SO_2 EKC are robust in four BASIC countries. Moreover our result provide no evidence that trade plays a role in shaping the EKC. This finding is also supported by the existing literature such as Cole (2004), and Kearsley and Riddel (2010).

Table 2.20 CO_2 emissions and trade

EKC: the conventional EKC regression equation
G.K.: Grossman and Krueger (1991) specification
S.C.: Suri and Chapman (1998) specification
Cole: Cole (2004) specification
Man. Ex.: Manufacturing Exports. Man. Im.: Manufacturing Imports.
Turning point income is in the unit of $, constant 2000 international dollar.
Number of leads and lags of DOLS are selected by Schwarz Information Criterion (SIC) and reported in [ ] in the form of [leads, lags].
, **, *, represent significance level of 10%, 5% and 1% respectively.*

Brazil	EKC [0, 0]	G.K. [0, 0]	S.C. [0, 0]	Cole [0, 0]
Constant	-30.0468*	-29.1648	-33.4805**	-89.4832
GDP	7.7983**	7.5741*	8.4047**	20.8418
GDP squared	-0.4078*	-0.3948*	-0.4294**	-1.1136
GDP cubed				
Open		0.0309	-0.0014	0.0800
Man. Share			-0.0908	-0.3411
Man. Ex.			-0.0174	
Man. Im.			0.1053	
Dirty exports				0.2453
Dirty imports				-0.1475
EKC relation	Inverted U	Inverted U	Inverted U	NA
Turning point	14,196.7663	14,651.8990	17,793.0399	NA

Table 2.20 CO_2 emissions and trade (continues)

China	EKC [1, 0]	G.K. [0, 2]	S.C. [0, 0]	Cole [1, 1]
Constant	-0.2848	14.4805*	37.8624	-12.8315
GDP	1.6900***	1.9785**	11.6731	3.2270
GDP squared	-0.0823*	-0.0946**	-0.3158	-0.2095
GDP cubed				
Open		0.0635	0.3567	0.1319
Man. Share			1.9985*	2.2914*
Man. Ex.			0.1105	-0.4527
Man. Im.			-0.1868	0.3528
Dirty exports				
Dirty imports				
EKC relation	Inverted U	Inverted U	NA	NA
Turning point	28,936.3804	34,783.4827	NA	NA

India	EKC [0, 0]	G.K. [2, 0]	S.C. [0, 0]	Cole [0, 0]
Constant	-12.5941	-38.8555*	-36.0433	-42.5183
GDP	4.5755*	11.1158**	9.9379**	12.4826*
GDP squared	-0.2771*	-0.6712**	-0.6032**	-0.8036*
GDP cubed				
Open		0.1027	-0.1393	-0.0280
Man. Share			0.7298	0.2506
Man. Ex.			0.1012	
Man. Im.			0.1455	0.1826
Dirty exports				0.0558
Dirty imports				
EKC relation	Inverted U	Inverted U	Inverted U	Inverted U
Turning point	3,854.9275	3,944.1438	3,782.9166	2,359.6071

South Africa	EKC [0, 0]	G.K. [0, 0]	S.C. [0, 1]	Cole [0, 0]
Constant	-36.7844	-103.9296	-182.6642	223.9904
GDP	9.3220*	24.2691	40.5774*	49.2641
GDP squared	-0.4708*	-1.3062	-2.1921*	-2.7168
GDP cubed				
Open		0.1114	-0.4362	-0.0932
Man. Share			1.2572	0.0247
Man. Ex.			0.1106	
Man. Im.			0.4521	
Dirty exports				0.2429
Dirty imports				0.4592
EKC relation	Inverted U	NA	Inverted U	NA
Turning point	19,944.0070	NA	10,459.5723	NA

Table 2.21 SO_2 emissions and trade

EKC: the conventional EKC regression equation
G.K.: Grossman and Krueger (1991) specification
S.C.: Suri and Chapman (1998) specification
Cole: Cole (2004) specification
Man. Ex.: Manufacturing Exports. Man. Im.: Manufacturing Imports.
Turning point income is in the unit of $, constant 2000 international dollar.
Number of leads and lags of DOLS are selected by Schwarz Information Criterion (SIC) and reported in [ ] in the form of [leads, lags].
, **, *, represent significance level of 10%, 5% and 1% respectively.*

Brazil	EKC [2, 1]	G.K. [2, 0]	S.C. [0, 0]	Cole [0, 0]
Constant	-176.1094***	-146.6411***	-94.6777***	-161.2222
GDP	40.7933***	34.0140***	21.6187***	37.6878
GDP squared	-2.3286***	-1.9318***	-1.1917***	-2.1502
GDP cubed				
Open		-0.2098*	-0.2055	-0.4277*
Man. Share			0.0032	0.0293
Man. Ex.			-0.1068	
Man. Im.			-0.0417	
Dirty exports				0.3956
Dirty imports				-0.4445
EKC relation	Inverted U	Inverted U	Inverted U	NA
Turning point	6,368.8108	6,659.3388	8,692.5069	NA

China	EKC [1, 2]	G.K. [0, 2]	S.C. [0, 0]	Cole [0, 0]
Constant	-36.7000**	-37.9711	-132.3883*	-498.7669
GDP	15.9484**	15.3658	47.0205*	187.4888
GDP squared	-2.1732*	-1.9101	-5.4699	-23.3265
GDP cubed	0.0996*	0.0775	0.2064	0.9607
Open		0.0419	0.0875	-0.4104
Man. Share			0.8690*	0.8276
Man. Ex.			0.0556	
Man. Im.			-0.1146	
Dirty exports				0.0873
Dirty imports				0.1175
EKC relation	Positive linear	NA	Positive linear	NA
Turning point	NA	NA	NA	NA

Table 2.21 SO_2 emissions and trade (continues)

India	EKC [2, 0]	G.K. [2, 0]	S.C. [0, 0]	Cole [1, 0]
Constant	-49.0006***	-50.7822***	-67.7186***	-59.9431***
GDP	12.7959***	13.2802***	18.2443***	15.8681***
GDP squared	-0.8070***	-0.8372***	-1.1976***	-1.0195***
GDP cubed				
Open		-0.0463	0.0842	0.0268
Man. Share			-0.2452	-0.0761
Man. Ex.			-0.0637	
Man. Im.			0.1376	
Dirty exports				-0.0385
Dirty imports				0.0345
EKC relation	Inverted U	Inverted U	Inverted U	Inverted U
Turning point	2,774.1652	2,782.0887	2,032.8016	2,397.2334

South Africa	EKC [0, 0]	G.K. [0, 0]	S.C. [0, 0]	Cole [0, 0]
Constant	-148.7523**	-134.4408*	-237.6339	11073.8300
GDP	33.2079**	30.0417*	51.8706	-2452.5020
GDP squared	-1.8005**	-1.6231*	-2.8761	135.7201
GDP cubed				
Open		-0.0491	-0.4597	-0.0624
Man. Share			0.3481	-3.0719
Man. Ex.			0.1303	
Man. Im.			0.2299	-0.5983
Dirty exports				4.8409
Dirty imports				
EKC relation	Inverted U	Inverted U	NA	NA
Turning point	10,114.3660	10,449.6759	NA	NA

2.6. Conclusion

Brazil, China, India and South Africa have become known as the BASIC bloc in international climate negotiations. It is little surprise that these four countries have found common ground in their positions on curbing carbon emissions. They share many similarities in their past experience and current circumstances. Over the last half century, they have grown to become, respectively, the largest economy in Latin America, East Asia, South Asia, and the second largest and most stable economy in Africa. However, rapid economic growth also means that they are now responsible for the largest share of the increase in global carbon emissions. In past climate negotiations, the BASIC countries emphasised two points: First, as developing countries they have to give priority to development and poverty reduction. Second, developed countries are mostly responsible for the current levels of CO_2 concentration in the atmosphere. Developed countries have the historical responsibility and can afford to do more in cutting emissions.

In the environmental economics literature, support for the BASIC countries' argument can be found in the form of the environmental Kuznets curve (EKC) hypothesis and the pollution haven hypothesis (PHH). The EKC postulates an inverted U-shaped relation between income and pollution. The PHH asserts the specialisation of dirty or clean industries depends on the relative stringency of environmental regulations between countries. However, previous empirical studies provide ambiguous results about the relationship between economic growth, international trade and environmental degradation. Focusing on the four developing countries, this chapter first investigates the causal relationship between economic growth, international trade and environmental degradation, then tests the Environmental Kuznets Curve (EKC) hypothesis, which is followed by an empirical study of the impacts of international trade on pollution.

This chapter makes several contributions to the literature. First, existing studies about the causal relationship between economic growth, international trade and environmental degradation provide mixed results. Insufficient research has been done on the BASIC countries, especially in view of weight wielded by these countries in international climate negotiations and environmental issues. Our study focuses exclusively on the BASIC countries, and finds unidirectional causality from GDP to CO_2 and SO_2 emissions. Second, this chapter shows that the homogeneity assumption implied by panel analysis may be too restrictive to generate informative results in EKC-type studies. We find that although BASIC countries are all emerging economies, each of them has different EKC shapes with different turning points. Third, we also find that the shape of EKC varies between different pollutants, i.e. CO_2 and SO_2 emissions. Four, we empirically show that dirty industry shares are decreasing in all four BASIC countries, implying the composition effect is not the main contributing factor for BASIC countries' pollution, and therefore neither PHH nor FEH is supported by our empirical results. Lastly, we provide no empirical evidence that international trade has effect on pollution or plays a role in the shaping of EKC for BASIC countries, supporting the finding by Cole (2004) and Kearsley and Riddel (2010) for developed countries. To sum up, our results provide evidence that economic growth in four developing countries may not follow a sustainable development path, but there is no evidence that international trade is bad for sustainable development.

The interpretation of the results in this chapter is subject to a number of caveats. Firstly, we exclusively focus on two pollutants: CO_2 emissions and SO_2 emissions. As argued in Dasgupta, et al. (2002) and de Bruyn and Heintz (2002), the relationship between economic growth, international trade and environmental degradation may not be with the same for different environmental indicators. Secondly, we exclusively focus on the BASIC countries. Since the relationship between economic growth, international trade and environmental degradation may vary across countries (de Bruyn, 1998; Stern et al. 1996 and Dasgupta et al., 2002, and de Bruyn and Heintz, 2002 among others), the results obtained in this chapter cannot be extrapolated to other countries without qualification. Lastly, due to data constraint, our study on the effects of trade on pollution is limited both in time span and in the range of industries covered. Therefore, the results must be treated as preliminary. Further research into the issue is needed and will require data on trade flows at a more disaggregated level.

Notes of Chapter 2

Note 1: Classification of sectors

Agriculture Value Added (% of GDP): Agriculture corresponds to ISIC divisions 1-5 and includes forestry, hunting, and fishing, as well as cultivation of crops and livestock production. Value added is the net output of a sector after adding up all outputs and subtracting intermediate inputs. It is calculated without making deductions for depreciation of fabricated assets or depletion and degradation of natural resources. The origin of value added is determined by the ISIC, revision 3. Note: For VAB countries, gross value added at factor cost is used as the denominator.

Industry value added (% of GDP): Industry corresponds to ISIC divisions 10-45 and includes manufacturing (ISIC divisions 15-37). It comprises value added in mining, manufacturing (also reported as a separate subgroup), construction, electricity, water, and gas. Value added is the net output of a sector after adding up all outputs and subtracting intermediate inputs. It is calculated without making deductions for depreciation of fabricated assets or depletion and degradation of natural resources. The origin of value added is determined by the International Standard Industrial Classification (ISIC), revision 3. Note: For VAB countries, gross value added at factor cost is used as the denominator.

Manufacturing value added (% of GDP): Manufacturing refers to industries belonging to ISIC divisions 15-37. Value added is the net output of a sector after adding up all outputs and subtracting intermediate inputs. It is calculated without making deductions for depreciation of fabricated assets or depletion and degradation of natural resources. The origin of value added is determined by the International Standard Industrial Classification (ISIC), revision 3. Note: For VAB countries, gross value added at factor cost is used as the denominator.

Services, etc., value added (% of GDP): Services correspond to ISIC divisions 50-99 and they include value added in wholesale and retail trade (including hotels and restaurants), transport, and government, financial, professional, and personal services such as education, health care, and real estate services. Also included are imputed bank service charges, import duties, and any statistical discrepancies noted by national compilers as well as discrepancies arising from rescaling. Value added is the net output of a sector after adding up all outputs and subtracting intermediate inputs. It is calculated without making deductions for depreciation of fabricated assets or depletion and degradation of natural resources. The industrial origin of value added is determined by the International Standard Industrial Classification (ISIC), revision 3. Note: For VAB countries, gross value added at factor cost is used as the denominator.

Note 2: ISIC divisions structure

ISIC Rev.3.1

(International Standard Industrial Classification of All Economic Activities, Rev.3.1)

- A - Agriculture, hunting and forestry
    - 01 - Agriculture, hunting and related service activities
    - 02 - Forestry, logging and related service activities
- B - Fishing
    - 05 - Fishing, aquaculture and service activities incidental to fishing
- C - Mining and quarrying
    - 10 - Mining of coal and lignite; extraction of peat
    - 11 - Extraction of crude petroleum and natural gas; service activities incidental to oil and gas extraction, excluding surveying
    - 12 - Mining of uranium and thorium ores
    - 13 - Mining of metal ores
    - 14 - Other mining and quarrying
- D - Manufacturing
    - 15 - Manufacture of food products and beverages
    - 16 - Manufacture of tobacco products
    - 17 - Manufacture of textiles
    - 18 - Manufacture of wearing apparel; dressing and dyeing of fur
    - 19 - Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harness and footwear
    - 20 - Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
    - 21 - Manufacture of paper and paper products
    - 22 - Publishing, printing and reproduction of recorded media
    - 23 - Manufacture of coke, refined petroleum products and nuclear fuel
    - 24 - Manufacture of chemicals and chemical products
    - 25 - Manufacture of rubber and plastics products
    - 26 - Manufacture of other non-metallic mineral products
    - 27 - Manufacture of basic metals

    - 28 - Manufacture of fabricated metal products, except machinery and equipment
    - 29 - Manufacture of machinery and equipment n.e.c.
    - 30 - Manufacture of office, accounting and computing machinery
    - 31 - Manufacture of electrical machinery and apparatus n.e.c.
    - 32 - Manufacture of radio, television and communication equipment and apparatus
    - 33 - Manufacture of medical, precision and optical instruments, watches and clocks
    - 34 - Manufacture of motor vehicles, trailers and semi-trailers
    - 35 - Manufacture of other transport equipment
    - 36 - Manufacture of furniture; manufacturing n.e.c.
    - 37 - Recycling
- E - Electricity, gas and water supply
    - 40 - Electricity, gas, steam and hot water supply
    - 41 - Collection, purification and distribution of water
- F - Construction
    - 45 - Construction
- G - Wholesale and retail trade; repair of motor vehicles, motorcycles and personal and household goods
    - 50 - Sale, maintenance and repair of motor vehicles and motorcycles; retail sale of automotive fuel
    - 51 - Wholesale trade and commission trade, except of motor vehicles and motorcycles
    - 52 - Retail trade, except of motor vehicles and motorcycles; repair of personal and household goods
- H - Hotels and restaurants
    - 55 - Hotels and restaurants
- I - Transport, storage and communications
    - 60 - Land transport; transport via pipelines
    - 61 - Water transport
    - 62 - Air transport
    - 63 - Supporting and auxiliary transport activities; activities of travel agencies
    - 64 - Post and telecommunications

- J - Financial intermediation
    - 65 - Financial intermediation, except insurance and pension funding
    - 66 - Insurance and pension funding, except compulsory social security
    - 67 - Activities auxiliary to financial intermediation
- K - Real estate, renting and business activities
    - 70 - Real estate activities
    - 71 - Renting of machinery and equipment without operator and of personal and household goods
    - 72 - Computer and related activities
    - 73 - Research and development
    - 74 - Other business activities
- L - Public administration and defence; compulsory social security
    - 75 - Public administration and defence; compulsory social security
- M - Education
    - 80 - Education
- N - Health and social work
    - 85 - Health and social work
- O - Other community, social and personal service activities
    - 90 - Sewage and refuse disposal, sanitation and similar activities
    - 91 - Activities of membership organizations n.e.c.
    - 92 - Recreational, cultural and sporting activities
    - 93 - Other service activities
- P - Activities of private households as employers and undifferentiated production activities of private households
    - 95 - Activities of private households as employers of domestic staff
    - 96 - Undifferentiated goods-producing activities of private households for own use
    - 97 - Undifferentiated service-producing activities of private households for own use
- Q - Extraterritorial organizations and bodies
    - 99 - Extraterritorial organizations and bodies

Appendix 2.1: Granger causality empirical studies

Table 1: Studies of causality between economic growth and international trade

Author	Country and span	Data and Property	Treatment	Growth	Trade	Pollution	Technique	Conclusion
Abhayaratne (1996)	Sri Lanka 1960 – 1992	Annual data, non-stationary, cointegration	Logarithmic first difference and error correction	GDP	Exports, imports		VECM Granger causality test	No evidence of any causality
Ahmad & Kwan (1991)	47 countries in Africa (no South Africa) 1981 – 1987	Annual data no formal test for stationarity	Logarithmic first difference	GDP per capita	Exports and manufactured exports		VAR Granger causality test for pooled cross countries	No evidence of any causality
Ahmad et al (2003)	Pakistan 1972 – 2001	Annual data, non-stationary, cointegration	No treatment for data, TY test	Manufacturing production	Exports		VAR Granger causality test	Unidirectional causality from export to manufacturing production
Alici & Ucal (2003)	Turkey 1987 – 2002	Quarterly data ADF shows non-stationary but PP test shows stationary	No treatment for data, TY test	Industrial production	Exports, FDI		VAR Granger causality test	Unidirectional causality from export to industrial production
Bahmani-Oskooee et al (1991)	20 countries (including Brazil) 1950 – 1987	Annual data, non-stationarity	Logarithmic first difference	GDP	Exports		VAR Granger causality test for each country	Heterogeneous causalities cross countries

Table 1: Studies of causality between economic growth and international trade (continues)

Author	Country and span	Data and Property	Treatment	Growth	Trade	Pollution	Technique	Conclusion
Bahmani-Oskooee & Alse (1993)	9 countries (including South Africa) 1973 – 1988	Quarterly data, non-stationarity, cointegration	Logarithmic first difference and error correction	GDP	Exports		VECM Granger causality test for each country	Bidirectional causality from export growth to output growth
Chebbi et al (2010)	Tunisia 1961 – 2004	Annual data, non-stationarity, cointegration	Logarithmic first difference and error correction	GDP per capita	Trade openness ratio	CO_2 emissions per capita	VECM Granger causality test	Bidirectional causalities between GDP, CO_2 emissions and Openness
Chimobi & Uche (2010)	Nigeria 1970 – 2005	Annual data, non-stationary but no cointegration	Logarithmic first difference	GDP	Exports		VAR Granger causality test	No evidence of any causality
Chow (1987)	8 countries (including Brazil) 1960 – 1980	Annual data no discussion of stationarity	No treatment for data, including future lags for Granger causality (Sims, 1972)	Manufacturing output	Exports		VAR causality test for each countries	Heterogeneous causalities cross countries, bidirectional causalities in 4 out of 8 countries
Cuadros et al (2004)	Argentina, Brazil, Mexico 1975 – 1997	Quarterly data, non-stationary, cointegration	Logarithmic first difference and error correction	Domestic income	Exports, FDI		VECM Granger causality test for each country	Heterogeneous causalities cross countries Unidirectional causality from export to domestic income in Brazil

Table 1: Studies of causality between economic growth and international trade (continues)

Author	Country and span	Data and Property	Treatment	Growth	Trade	Pollution	Technique	Conclusion
Deme (2002)	Nigeria 1970 – 1997	Quarterly data, non-stationary, cointegration	Logarithmic first difference and error correction	GDP	Exports, imports, trade volume, exports ratio, imports ratio, trade openness ratio		VECM Granger causality test	Bidirectional causalities between trade volume and GDP, trade openness ratio and GDP
Dritsaki et al (2004)	Greece 1960 – 2002	Annual data, non-stationary, cointegration	Logarithmic first and error correction	GDP	Exports, FDI		VECM Granger causality test	Bidirectional causalities between GDP and exports, unidirectional causality from FDI to GDP
Dutt & Ghosh (1996)	26 countries (including Brazil, India, South Africa) 1953 – 1991	Annual data, non-stationary, cointegration	Logarithmic first difference and error correction	GDP	Exports		VECM Granger causality test for each country	Heterogeneous causalities. No evidence of Granger causality in Brazil, India, South Africa
Ghartey (1993)	Japan 1955 – 1991 Taiwan, US 1960 – 1990	Quarterly data, non-stationary	Logarithmic difference and Wald test for Granger causality (Hsiao, 1979)	GNP	Exports		VAR Granger causality test for each country	Heterogeneous causalities cross countries
Gordon & Sakyi-Bekoe (1993)	Ghana 1955 – 1987	Annual data, non-stationary	Logarithmic first difference	GDP	Exports		5 causality testing procedures	Causality test results are sensitive to testing procedures

Table 1: Studies of causality between economic growth and international trade (continues)

Author	Country and span	Data and Property	Treatment	Growth	Trade	Pollution	Technique	Conclusion
Halicioglu (2009)	Turkey 1960 – 2005	Annual data, non-stationary, cointegration	Logarithmic first difference and error correction	GDP per capita	Trade openness ratio	CO2 emissions per capita	VECM Granger causality test	Bidirectional causalities between GDP and CO2 emissions
Hsiao & Hsiao (2006)	8 countries (including China) 1986 – 2004	Annual data, non-stationary, cointegration	Logarithmic first difference	GDP	Exports, FDI		VAR Granger causality test for each country; Panel VAR Granger causality test	Bidirectional causality between GDP and Exports, unidirectional causality from FDI to GDP Unidirectional causality from GDP to FDI, and Exports to FDI in China
Jin & Yu (1996)	US 1960 – 1987	Quarterly data, non-stationary	Logarithmic first difference	GDP	Exports		VAR Granger causality test	No evidence of any causality
Jung & Marshall (1985)	37 countries (including Brazil, India, South Africa) 1950 – 1985	Annual data with no formally tested stationarity	Growth rate series are used to avoid suspected non-stationarity problem	Output growth rate measured by the annual percentage change in real GNP (or GDP)	Exports growth rate measured by annual percentage change in real exports		VAR Granger causality test for each country	Heterogeneous causalities cross countries No evidence of causality in Brazil, India. Unidirectional causality from output growth to exports growth in South Africa

Table 1: Studies of causality between economic growth and international trade (continues)

Author	Country and span	Data and Property	Treatment	Growth	Trade	Pollution	Technique	Conclusion
Khan et al (1995)	Pakistan 1972 – 1994	Quarterly data, non-stationary, cointegration	Logarithmic first difference and error correction	GDP	Exports		VAR Granger causality test	Bidirectional causality between growth and export
Kunst & Marin (1989)	Austria 1956 – 1985	Quarterly data with no formally tested non-stationarity	Logarithmic first difference	Productivity measured by output per employee in manufacturing sector	Manufacturing goods exports		VAR Granger causality test	No evidence of any causality
Lee (2009)	Malaysia 1970 – 2000	Annual data ARDL shows non-stationary and cointegration	Logarithmic first difference and error correction	GDP per capita	FDI	CO_2 emissions per capita	VECM Granger causality test	Unidirectional causality from FDI to GDP, CO_2 emissions to GDP, and FDI to CO_2 emissions
Liu et al (1997)	China 1983 – 1995	Quarterly data, non-stationary, but no evidence of cointegration	Logarithmic first difference	GNP	Exports, imports, trade volume		4 causality testing procedures	Causality test results are sensitive to testing procedures Bidirectional causality between GNP and openness

Table 1: Studies of causality between economic growth and international trade (continues)

Author	Country and span	Data and Property	Treatment	Growth	Trade	Pollution	Technique	Conclusion
Liu et al (2002)	China 1981 – 1997	Quarterly data, non-stationary, cointegration	Logarithmic first difference and error correction	GDP	Exports, Imports, FDI		VECM Granger causality test	Bidirectional causalities between GDP, FDI and exports. Unidirectional causalities from GDP, FDI, exports to imports
Marin (1992)	Germany, Japan, UK, US, 1960 – 1987	Quarterly data, non-stationary, cointegration	Logarithmic difference and error correction	Manufacturing output per employee	Exports of manufacturing goods		VAR or VECM Granger causality test for each country	Unidirectional causality from exports to productivity
Narayan & Smyth (2009)	6 Middle Eastern countries 1974 – 2002	Annual data, non-stationary, cointegration	Logarithmic difference and error correction	GDP	Exports		Panel VECM Granger causality test	Unidirectional causality from exports to GDP
Oxley (1993)	Portugal 1865 – 1985	Annual data, non-stationary, cointegration	Logarithmic difference and error correction	GDP	Exports		VECM Granger causality test	Unidirectional causality from GDP to exports
Pop-Silaghi (2006)	Romania 1998 – 2004	Quarterly data, non-stationary, cointegration	Logarithmic difference and error correction	GDP	Exports, imports		VECM Granger causality test	Unidirectional causality from GDP to exports

Table 1: Studies of causality between economic growth and international trade (continues)

Author	Country and span	Data and Property	Treatment	Growth	Trade	Pollution	Technique	Conclusion
Serletis (1992)	Canada 1870 – 1985	Annual data, non-stationary, but no cointegration	Logarithmic first difference	GNP	Exports, imports		VAR Granger causality test	Unidirectional causality from export to GNP
Shan & Sun (1998)	China 1987 – 1996	Monthly data, non-stationary	No treatment for data, TY test for Granger causality	Industrial output	Exports		VAR Granger causality test	Bidirectional causality between GDP and exports
Sharma & Dhakal (1994)	30 countries (including India) 1960 – 1988	Annual data, non-stationary	Logarithmic first difference	GDP	Exports		VAR Granger causality test for each country	Heterogeneous causalities cross countries. Unidirectional causality from exports to GDP in India
Sharma et al (1991)	Germany, Italy, Japan, UK, US 1960 – 1987	Quarterly data no formally tested non-stationarity and seasonal effects	Logarithmic first or/and fourth differences	GNP	Exports		VAR Granger causality test for each country	Heterogeneous causalities cross countries
Thornton (1996)	Mexico 1895 – 1992	Annual data, non-stationary, cointegration	Logarithmic first difference and error correction	GDP	Exports		VECM Granger causality test	Unidirectional causality from exports to GDP

Table 2: Studies of causality between economic growth and CO2 emissions

Author	Country	Data Property	Treatment	Growth	Trade	Pollution	Technique	Conclusion
Ang (2008)	Malaysia 1971 – 1999	Annual data, non-stationary, cointegration	Logarithmic first and error correction	GDP per capita		CO2 emissions per capita	VECM Granger causality test	Unidirectional causality from CO2 emissions to GDP
Chang (2010)	China 1981 – 2006	Annual data, non-stationary, cointegration,	Logarithmic first difference and error correction	GDP		CO2 emissions	VECM Granger causality test	Unidirectional causality from GDP to CO2 emissions
Chebbi (2009)	Tunisia 1971 – 2004	Annual data, non-stationary, cointegration	Logarithmic first and error correction	GDP per capita		CO2 emissions per capita	VECM Granger causality test	Unidirectional causality from CO2 emissions to GDP
Chebbi et al (2010)	Tunisia 1961 – 2004	Annual data, non-stationarity, cointegration	Logarithmic first difference and error correction	GDP per capita	Trade openness ratio	CO2 emissions per capita	VECM Granger causality test	Bidirectional causalities between GDP, CO2 emissions and trade openness
Coondoo & Dinda (2002)	88 countries in 13 groups 1960 – 1990	Annual data no discussion of stationarity	No treatment	GDP per capita		CO2 emissions per capita	VAR Granger causality test	Heterogeneous causalities cross country groups
Day & Grafton (2002)	Canada 1958 – 1999	Annual data, non-stationary, no cointegration	Logarithmic first difference	GDP per capita		CO, CO2, SO2, emissions, TSP concentration	VAR Granger causality test	Bidirectional causalities between GDP and 4 pollutants
Ferda (2008)	Turkey 1960 – 2005	Annual data, non-stationary, cointegration	Logarithmic first difference and error correction	Gross national income per capita		CO2 emissions per capita	VECM Granger causality test	Bidirectional causality between income and CO2 emissions

Table 2: Studies of causality between economic growth and CO2 emissions (continues)

Author	Country	Data Property	Treatment	Growth	Trade	Pollution	Technique	Conclusion
Fodha & Zaghdoud (2010)	Tunisia 1961 – 2004	Annual data, non-stationary, cointegration	Logarithmic first difference and error correction	GDP per capita		CO2, SO2 emissions per capita	VECM Granger causality test	Unidirectional causality from GDP to CO2 and SO2 emissions
Halicioglu (2009)	Turkey 1960 – 2005	Annual data, non-stationary, cointegration	Logarithmic first difference and error correction	GDP per capita	Trade openness ratio	CO2 emissions per capita	VECM Granger causality test	Bidirectional causalities between GDP and CO2 emissions
Hatzigeorgiou et al (2011)	Greece 1977 – 2007	Annual data, non-stationary, cointegration	Logarithmic first difference and error correction	GDP		CO2 emissions	VECM Granger causality test	Unidirectional causality from GDP to CO2 emissions
Lee (2009)	Malaysia 1970 – 2000	Annual data ARDL shows non-stationary and cointegration	Logarithmic first difference and error correction	GDP per capita	FDI	CO2 emissions per capita	VECM Granger causality test	Unidirectional causality from FDI to GDP, CO2 emissions to GDP, and FDI to CO2 emissions
Maddison & Rehdanz (2008)	134 countries in 13 groups (including Brazil, China, India, South Africa) 1990 – 2005	Annual data, non-stationary, cointegration	Logarithmic first difference and error correction	GDP per capita		CO2 emissions per capita	Panel VECM Granger causality test	Bidirectional causality between GDP and CO2 emissions

Table 2: Studies of causality between economic growth and CO2 emissions (continues)

Author	Country	Data Property	Treatment	Growth	Trade	Pollution	Technique	Conclusion
Menyah & Wolde-Rufael (2010)	US 1960 – 2007	Annual data, non-stationary	No treatment for data, TY test for Granger causality	GDP		CO2 emissions	VAR Granger causality test	Bidirectional causality between GDP and CO2 emissions
Pao & Tsai (2011)	4 BRIC countries: Brazil, Russian, India, China 1980 – 2007	Annual data, non-stationary, cointegration	Logarithmic first difference and error correction	GDP per capita	FDI	CO2 emissions per capita	Panel VECM Granger causality test	Bidirectional causality between CO2 emissions and GDP, CO2 emissions and FDI
Peng & Sun (2010)	1952 – 2007	Annual data, non-stationary, cointegration	No treatment for data, TY test for Granger causality	GDP		CO2 emissions	VAR Granger causality test	Bidirectional causality between GDP and CO2 emissions
Soytas et al (2007)	US 1960 – 2004	Annual data, non-stationary	No treatment for data, TY test for Granger causality	GDP		CO2 emissions	VAR Granger causality test	No evidence of causality between GDP and CO2 emissions
Soytas & Sari (2009)	Turkey 1960 – 2000	Annual data, non-stationary	No treatment for data, TY test for Granger causality	GDP per capita		CO2 emissions	VAR Granger causality test	No evidence of causality between GDP and CO2 emissions
Tiwari (2011)	India 1971 – 2007	Annual data, non-stationary, no cointegration	Logarithmic first difference	GDP		CO2 emissions	VAR Granger causality test	No evidence of causality between GDP and CO2 emissions
Zhang & Cheng (2009)	China 1960 – 2007	Annual data, non-stationary	No treatment for data, TY test for Granger causality	GDP		CO2 emissions	VAR Granger causality test	No evidence of causality between GDP and CO2 emissions

Table 3: Studies of causality between international trade and CO2 emissions

Author	Country	Data Property	Treatment	Growth	Trade	Pollution	Technique	Conclusion
Chebbi et al (2010)	Tunisia 1961 – 2004	Annual data, non-stationarity, cointegration	Logarithmic first difference and error correction term	GDP per capita	Trade openness ratio	CO2 emissions per capita	VECM Granger causality test	Bidirectional causalities between GDP, CO2 emissions and trade openness
Halicioglu (2009)	Turkey 1960 – 2005	Annual data, non-stationary, cointegration	Logarithmic first difference and error correction	GDP per capita	Trade openness ratio	CO2 emissions per capita	VECM Granger causality test	Bidirectional causalities between GDP and CO2 emissions
Hoffmann et al (2005)	112 countries in 3 groups 1971 – 1999	Annual data, non-stationary	Logarithmic first difference		FDI	CO2 emissions	Panel Granger causality	Unidirectional causality from CO2 to FDI in low-income countries Unidirectional causality from FDI to CO2 in middle-income countries
Lee (2009)	Malaysia 1970 – 2000	Annual data ARDL shows non-stationary and cointegration	Logarithmic first difference and error correction	GDP per capita	FDI	CO2 emissions per capita	VECM Granger causality test	Unidirectional causality from FDI to GDP, CO2 emissions to GDP, and FDI to CO2 emissions

Table 3: Studies of causality between international trade and CO2 emissions

Author	Country	Data Property	Treatment	Growth	Trade	Pollution	Technique	Conclusion
Chebbi et al (2010)	Tunisia 1961 – 2004	Annual data, non-stationarity, cointegration	Logarithmic first difference and error correction term	GDP per capita	Trade openness ratio	CO2 emissions per capita	VECM Granger causality test	Bidirectional causalities between GDP, CO2 emissions and trade openness
Halicioglu (2009)	Turkey 1960 – 2005	Annual data, non-stationary, cointegration	Logarithmic first difference and error correction	GDP per capita	Trade openness ratio	CO2 emissions per capita	VECM Granger causality test	Bidirectional causalities between GDP and CO2 emissions
Hoffmann et al (2005)	112 countries in 3 groups 1971 – 1999	Annual data, non-stationary	Logarithmic first difference		FDI	CO2 emissions	Panel Granger causality	Unidirectional causality from CO2 to FDI in low-income countries Unidirectional causality from FDI to CO2 in middle-income countries
Lee (2009)	Malaysia 1970 – 2000	Annual data ARDL shows non-stationary and cointegration	Logarithmic first difference and error correction	GDP per capita	FDI	CO2 emissions per capita	VECM Granger causality test	Unidirectional causality from FDI to GDP, CO2 emissions to GDP, and FDI to CO2 emissions

Chapter 3: The Environmental Impact of International Trade in Chinese Provinces

3.1 Introduction

This chapter examines the effect of international trade on environmental degradation, more specifically that on pollution emissions in Chinese provinces. As one of the major emerging economies in the world, China's environmental issues have always attracted much attention. Over the past three decades (1980s-2010s), the Chinese economy was characterised by rapid economic growth, strong expansion in international trade and growing environmental problems. At the same time, it has also seen significant regional disparities in economic growth, environmental degradation, and trade and FDI inflows. The role of trade on growth is a mixed proposition at best (Frankel and Romer, 1999), but the increase in environmental degradation in China following her "opening up" policy suggests a possible link between international trade and environmental degradation. This chapter examines and argues that the environmental impact of international trade in China results from the trade induced changes in industrial structure as predicted by the theory of comparative advantage.

A number of previous studies on the relationship between trade and the environment have identified two main sources of comparative advantage: the pollution haven effect (PHE hereafter) and factor endowment effect (FEE hereafter), which originate respectively from the Pollution Haven Hypothesis (PHH hereafter) and Factor Endowment Hypothesis (FEH hereafter). The PHE refers to the comparative advantage rising from the relative stringency of environmental regulations. In China, low (high) income provinces are believed to have lenient (stricter) environmental regulations, so they have a comparative advantage in polluting (clean) production process. Thus the PHE implies that China's international trade leads to low income provinces specialising in dirty goods production and becoming pollution havens. By contrast, the FEE argues that specialisation in dirty production is driven by relative capital abundance. Since high income provinces are believed to be more capital abundant, high income provinces have comparative advantage in producing dirty goods (Copeland and Taylor, 2004). Thus the FEE predicts China's international trade leading to high income provinces specialising in dirty goods production and becoming pollution havens. Since the environmental impact of international trade in China is potentially determined by both effects, an empirical evaluation of these two opposite effects is necessary.

In this chapter we carry out an empirical study of the effect of international trade on the natural environment at China's provincial level. To disentangle the Pollution

Haven Effect (PHE) and Factor Endowment Effect (FEE), we follow an empirical model proposed by Antweiler et al. (2001) and Cole and Elliott (2003). Previous empirical studies at national level such as Antweiler et al. (2001) and Cole and Elliott (2003), have shown that international trade reduces pollution in low capital to labour ratio and high income countries, but raises pollution in high capital to labour ratio and low income countries. We find that previous finding at national level does not hold at China's provincial level. Instead, our results suggest that international trade is good for the environment in Chinese provinces. In provinces with low capital to labour ratio, the composition effect induced by FDI inflows is negative to pollution, while in provinces with high capital to labour ratio and income, both composition and technique effects are negative to pollution.

The contribution of this chapter to the existing literature is threefold. First, official statistics on the emissions of waste gas, waste water and solid waste in Chinese provinces are available for the period of 1985–2010. Previous studies at China's provincial level only cover a fraction of the 26-year period (typically 10 to 15 years). Our study covers the entire period. Second, existing studies utilising a fraction of our data set find ambiguous results on the relationship between international trade and pollution. However, utilising the full data set, we find clear evidence that trade openness and FDI inflows are good for the environment (reducing pollution) in Chinese provinces, indicating international trade does not lead to Chinese provinces becoming pollution havens. Third, theoretical studies in this strand of literature often presume that high capital to labour ratio means high pollution intensity. Previous empirical studies usually support this assumption. However, our study questions this assumption and provides evidence that high capital to labour ratio may not necessarily mean high pollution intensity, at least not so for China.

The remainder of this chapter is organised as follows. Section 3.2 first discusses the hypothesised relationship between trade and the environment, followed by a brief review of previous studies. The last part of the section examines the existing empirical studies especially on China. Section 3.3 provides a historical review of China's economic reform, opening up policy and current environmental issues. Section 3.4 outlines the theoretical framework and empirical methodology. Section 3.5 presents our results, and Section 3.6 concludes.

3.2 Trade and the environment

Is international trade good or bad for the environment? The answer of this question is not so straightforward. Opponents of free trade claim that international trade is obviously bad for the environment, since a rise in international trade, increases economic growth, increases production and consumption, increases energy use and climate change (Korves et al., 2011). However, in the view-point of optimists, trade is the best way to protect the environment, since international trade is a necessary component in catalysing economic growth, therefore trade is critical in providing the economic means that enable countries to enhance environmental protection (Eiras and Schaefer, 2001). Both arguments from opponents and proponents of international trade sound credible, revealing that the trade-environment relationship is complicated and the environmental impact of international trade is influenced by contradictory effects. Selectively, we review some of the contradictory effects in this section.

Firstly, as discussed in many academic studies, international trade can stimulate economic growth (the important publications are Barro, 1991, Edwards, 1992, 1993, and 1998, Sachs and Warner, 1995, Krueger, 1997, Frankel and Romer, 1999, Dollar and Kraay, 2004, Winters, 2004, Wacziarg and Welch, 2008). On the one hand, economic growth scales up economic activities, increasing production and consumption, and causing resource depletion and pollution, since economic activities use the environment service as an input factor (consumption of natural resource) as well as a dump for waste. As argued by Grossman and Krueger (1995), "[I]f the composition of output and the methods of production were immutable, then damage to the environment would be inextricably linked to the scale of global economic activity". Thus, international trade can have a detrimental effect on the environment through the "scale effect", if international trade leads to an increase in the size of the economy. On the other hand, economic growth also raises a country's income level, which increases the consumer demand for clean environment and in turn increases consumers' willingness to pay for clean environment. As stated in the United Nations report (United Nations, 1987), the overriding priority of sustainable development should be given to meeting the essential needs of the world's poor, after which protecting the environment for meeting current and future needs comes at the second place. Thus poverty is a key contributor to the environmental degradation in many developing countries (Duraiappah, 1996, and Beghin, 2000), since poorer countries are more willing to sacrifice their natural environment for income. But when income reaches a certain level, consumers are more willing to sacrifice additional income for clean environment, generating pressure for polluting activities and forcing the pollution level to reduce. For instance, consumers can push government to impose stricter environmental regulations, stop buying goods from polluting producers, and donate to environmental groups for pollution reduction. Thus, international trade may also benefit the environment through the "income effect", if international trade raises the income level, that increases the willingness to pay for clean environment and in turn leads to pollution reduction. Therefore, the environmental effect of international trade through the channel of economic growth may be negative by the scale effect, but positive by the income effect.

The second channel, through which international trade may affect the environment, is international competition. International trade leads to competition in production activities as well as environmental policies. On the one hand, international trade introduces international competition for domestic firms, thus domestic firms will have more incentive to reduce their costs, leading to improvement in firms' efficiency and technology level. As trade liberalises, international competition becomes intense leading to reduction in prices and markups, which makes the less efficient firms lose out and forces firms to innovate (Chen et al, 2009). As a result, firms with the least productivity will exit the market, thus resources are reallocated to more productive firms (Pavcnik, 2002, Tybout, 2003 and Topalova, 2011). International trade not only clears out inefficient firms, but also forces the surviving firms to innovate more (Aw et al., 2011, and Bustos, 2011). Moreover, as public awareness rises, adopting more environmental friendly technology may raise the "Green" reputation of firms, which promotes their brands and creates incentives for technology upgrade (Chen, 2008). On the other hand, the international competition induced by international trade may have negative effects on the environment. If environmental policy is a source of comparative advantage, a rise in international competition will reduce the prices and markups of domestic firms, thus domestic firms may lobby more successfully to prevent the enactment of stringent environmental regulations (Binder and Neumayer, 2005), causing a regulation chill. Furthermore, governments may reduce their environmental regulations to protect the competiveness of domestic firms and attract foreign investment (as argued by the pollution haven effect), which leads to the "race to the bottom" environmental policies (Revesz, 1992 and Porter, 1999 among others). Therefore, as in the channel of economic growth, international competition introduced by international trade can lead to improvement as well as degradation in the environment.

Last but not least, international trade may also affect the environment through the composition effect. The composition effect induced by international trade is determined by countries' comparative advantage. Classical international trade theories maintain that trade is governed by comparative advantage. There are two rival hypotheses about the relationship between trade and the environment: Factor Endowment Hypothesis (FEH) and Pollution Haven Hypothesis (PHH). If a country has comparative advantage in capital (labour), then it is likely to specialise in the production of capital (labour) intensive goods and export dirty (clean) goods. Thus, for dirty goods exporting (importing) countries, international trade is likely to increase (reduce) pollution in these countries. It is widely believed that capital to labour ratio industries are more polluting than labour intensity industries, because from conventional wisdom, capital to labour ratio industries such as manufacturing industries, have more physical capital comparing with agriculture and service industries, at the same time consume more energy and generate more pollution (detail discussion see Antwerlier et al., 2001, Copeland and Taylor, 1997 and 2004). This is as predicted by the Factor Endowment Hypothesis (FEH). The FEH argues the source of comparative advantage is the factor endowment. Since developed countries are relatively capital abundant and developing countries are labour abundant, international trade will lead to developed countries specialising in dirty goods production and developing countries specialising in clean goods production. Thus trade causes pollution rise in developed countries but pollution reduction in developing countries. By contrast, the Pollution Haven Hypothesis (PHH) emphasises on the effect of environmental regulations and argues that lenient environmental regulations in developing countries give developing countries comparative advantage in producing dirty goods. As predicted by the PHH, holding other factors constant, international trade leads to developed countries specialising in clean goods production, exporting clean goods and importing dirty goods, since developed counties have stricter environmental regulations thus have comparative disadvantage in dirty goods production. Whereas, because developing countries have lenient environmental regulations, international trade leads to developing countries specialising in dirty good production, importing clean goods and exporting dirty goods. Therefore, the PHH posits that international trade causes developing countries becoming pollution havens (Copeland and Taylor, 2004).

In sum, it is not straightforward to say international trade is good or bad for the environment, because the environmental impact of international trade is subject to pairs of contradictory effects. Although some argue that the increasing international trade and globalisation enhance international cooperation on environmental issues, for instance international treaties may help to reduce world pollution level, and financial and technological aids from developed countries can help developing countries fight against their environmental problems, the net effect of international trade may still vary across countries depending on the interaction of aforementioned contradictory effects.

3.2.1 Empirical review

An extensive empirical literature exists on the Pollution Haven Hypothesis (PHH). Although the propositions of the PHH are not complicated, moving from statement to testing of the hypothesis using real world data has proven difficult. Empirical findings vary mainly due to differences in the method of estimation, type of data employed, time period selected and dimensions of the hypothesis investigated. Detailed reviews of the PHH studies are provided in Copeland and Taylor (2004) and Taylor (2005). Empirical studies of the PHH may be divided into three groups investigating respectively the relationships between country characteristics and environmental regulations, between environmental regulations on trade/FDI flows, and between trade/FDI flows and the environment.

The first group focuses on the channel from country characteristics to environmental regulations. As pointed out by Copeland and Taylor (1994) as well as many other theoretical studies, a nation's environmental policy is not randomly selected, instead it is determined by the nation's characteristics. Fredriksson and Mani (2004) argue a country's environmental policy making is influenced by its political uncertainty, government honesty and international trade. Utilising a cross country dataset of 26 OECD and 92 developing countries, Fredriksson and Mani (2004) find that a lower level of corruption tends to strengthen environmental policy; countries with more liberal trade policies, thus more economically integrated with the rest of the world, tend to set more stringent environmental policies; and moreover, the environmental stringency is higher in countries that are more open to trade as well as politically stable. Evidence of country characteristics influencing country environmental policy is not only found at the national level, but also at more disaggregated levels inside a nation, such as the county level. Becker (2004) examines the ways that community characteristics affect local pollution abatement using US plant-level data for the period 1979-1988. Becker (2004) finds four county characteristics have consistently statistically significant positive effect on plant-level abatement. These four characteristics are homeownership rate, income level, political ideology of the populace and whether the county is within a metropolitan statistical area. Becker also finds that the proportion of manufacturing workers has consistently negative effect on plant-level abatement.

Another group of empirical studies investigates the impact of environmental regulations on trade and FDI flows. In the line of studies on trade flows, Ederington et al (2004) study manufacturing imports in the US from 1978 to 1994. They find evidence supporting the PHH, since industries whose environmental costs rise also see an increase in their imports. However Ederington et al (2004) does not find any evidence that international trade has led to large volumes of dirty imports, instead international trade has shifted the US industrial composition towards dirtier industries. Mulatu et al (2004) investigate the impact of environmental regulations on industrial trade flows in the US, Germany and the Netherlands. They argue the reason why many empirical studies fail to find any evidence of the PHH may have resulted from failing to take into account some industry characteristics, such as the geographical 'footlooseness' of an industry. Tightening up environmental regulations is likely to have a greater impact on polluting industries that can relocate easily (more footloose) than on industries that are not 'footloose'. Mulatu et al (2004) find mixed results for their sample countries with various environmental indicators. On the one hand, the stringency of environmental policy is consistently found to be a source of comparative disadvantage for dirty industries in the US. On the other hand, there is no evidence of the PHH in Germany and the Netherlands, except in the wood and fabricated metal industries in the Netherlands. The estimation results of Mulatu et al (2004) accentuate the importance for empirical studies to allow for potential heterogeneity in the environmental effects between industries. Levinson and Taylor (2008) study the US-Canada and US-Mexico trade flows, utilising a dataset of the US environmental regulations and trade flows with Canada and Mexico for 130 manufacturing industries from 1977 to 1986. They first introduce a theoretical model demonstrating how unobserved heterogeneity, endogeneity and aggregation issues bias standard measurements of the relationship between environmental regulations and trade flows. Levinson and Taylor (2008) then derive an empirical specification and propose to use fixed effect instrumental variables approach to tackle potential pitfalls in estimation. Levinson and Taylor (2008) find a rise in pollution abatement cost in the US polluting industries increases the US dirty imports from both Canada and Mexico, indicating both Canada and Mexico may be pollution havens for the US polluting production.

In the line of empirical studies on FDI flows, Cole and Elliott (2005) find evidence of the pollution haven effect, since the level of pollution abatement cost in the US industries has statistically significant positive effect on the US outward FDI to Brazil and Mexico. At the state level, Keller and Levinson (2002) study pollution abatement cost and inward FDI into the US states, and find that abatement cost has a moderate deterrent effect on FDI. To examine the impact of environmental regulations on firms' investment decisions, Javorcik and Wei (2004) utilise a rich dataset of investment decisions by 534 major multinational firms in 25 transition economies in Central/Eastern Europe and the former Soviet Republics. After controlling for firm characteristics, such as size and R&D intensity, as well as host country controls such as openness, democracy and tax rates, Javorcik and Wei (2004) find some evidence that stronger environmental protection discourages investment in more polluting industries. However, this finding is not robust (see section 2.2 "Robust Checks and Extension" in Javorcik and Wei (2004)), so Javorcik and Wei (2004) conclude that their data indicate that host country environmental standards have very little impact on FDI inflows.

The third group of empirical studies examine the relationship between trade or FDI flows and pollution. So far, this is the largest group of the PHH empirical studies, and a large amount of publications can be put in this group. The logic behind this group of empirical studies is simple: the most direct way to see the effects of trade and FDI on the environment is to include them in the estimation equation. Because of the expansive ground covered by this group of studies, they have been further classified into three strands to facilitate the discussion. The first strand utilises various measures of international trade such as trade intensity (trade openness), tariff rates, Dollar's index of trade orientation and the parallel market premium, as well as a number of pollutants such as sulphur dioxide, carbon emissions, dark matter pollution and suspended particular matter (SPM). The main publications are Grossman and Krueger (1991), and Shafik and Bandyopadhyay (1992). Grossman and Krueger (1991) study the environmental impact of trade between the US and Mexico. They find that international trade may increase Mexico's specialisation in sectors that cause less than average amount of environmental damage, and the asymmetries in environmental regulations and enforcements between the US and Mexico play at most a minor role. Shafik and Bandyopadhyay (1992) investigate 10 environmental quality and pollution indicators utilising a data set of 149 countries for the period 1960-1990. They fail to reach unanimous conclusion for the trade effects on the environment, instead they find trade effects on the environment vary by environmental indicators: trade seems to improve forestation and human waste in rivers, but shows insignificant effect for most other environmental indicators.

Antweiler et al. (2001) propose to utilise interaction terms between trade openness and relative capital-labour ratio, and between trade openness and relative income level to estimate the trade induced composition effect and technique effect. They find trade induced effects are contribute significantly to sulphur dioxide (SO2) concentrations in

108 cities across 43 countries during 1971-1996. Cole and Elliott (2003) apply Antweiler et al. (2001) approach to four pollutants: BOD, CO2, NOx and SO2 in terms of emissions as well as concentration in 32 developed and developing countries covering the period 1975-1995. Their results generally support Antweiler et al. (2001)'s finding about sulphur dioxide in that both trade induced composition effect and technique effect are in operation, but tend to offset each other. However, Cole and Elliott (2003) find the magnitude and sign of trade induced effects vary by pollutants, indicating trade induced effects not affect pollutants in a uniform pattern. Thus Cole and Elliott (2003) conclude that the 'neat' results obtained by themselves and Antweiler et al. (2001) for sulphur dioxide may not necessarily hold for other pollutants, therefore further research on different environmental indicators are still required. Empirical studies in this strand also include Cole (2003) and Kellenberg (2008) among others.

The third strand of empirical studies proposes to utilise structural models to disentangle the trade induced effects. Dean (2002) introduces environmental damage into the Heckscher-Ohlin model, and derives a two-equation simultaneous system describing income growth and emissions growth. In Dean's two-equation simultaneous system, international trade affects emission growth both directly and indirectly. The indirect channel identifies trade induced environmental effect through income growth determination, whereas the direct channel identifies the trade effect through emission growth determination. Using a World Bank dataset of Chinese provincial-level water pollution spanning the period 1987-95, Dean (2002) finds that international trade positively raises emissions though the direct effect, but is beneficial to the environment through indirect effect, indicating freer trade aggravates environmental damage via the terms of trade, but mitigates environmental damage via income growth. Inspired by Dean's research, He (2007) constructs a four-equation simultaneous system to capture direct and indirect impacts of trade on emissions. In He's model, trade induced indirect effect is further decomposed into three effects: scale, composition and technique effect, as proposed by Grossman and Krueger (1991). He also considers the potential characteristics differences between exports and imports, since it is often observed in Asian countries' industrialisation histories that exports are stimulated by the world demand revealing country's comparative advantage whereas imports of machinery and equipment are used to expand dirty production (He, 2007). He's (2007) results suggest that China's exports are emissions reducing whereas imports (stock of imported machinery and equipment) are emissions increasing for industrial SO_2 emissions in the period of 1993-2001. Empirical studies in this strand also include Frankel and Rose (2002), Managi (2004), He (2006), and Managi et al. (2009) among others.

3.3 Economic growth, international trade and the environment in China

The aim of this section is to introduce the background information about economic growth, international trade and the environment in Chinese provinces. We first review briefly the economic reform process in China and its impact on China's trade flows and FDI inflows. And then the environmental issues and environmental regulations in China are also discussed. Last but not least, we also discuss the regional differences in income level, factor endowment, and enforcement of national environmental regulations and policy initiatives in this section.

3.3.1 China's economic reform and economic growth

Prior to 1978, China was an agriculture economy with low income level. Since the 3rd Plenary Session of the 11th Communist Party of China Central Committee in 1978, Chinese government has carried out an economic reform, introducing market principles and opening up China for trade and foreign investment, known as the "Socialism with Chinese characteristics". During this economic reform, China's central-plan form economy has been gradually reformed to a market-oriented economy. This nation-wide economic reform has brought China unprecedented double digit growth for about 30 years (IMF, 2014). As shown in figure 3.1, before the economic reform in 1978, both China's GDP and GDP per capita stagnated at a low level for almost 20 years. But since 1978, it has been seen an exponential growth in both China's GDP and GDP per capita. China's spectacular economic growth can be seen too in values and growth rates of GDP and GDP per capita as selectively reported in table 3.1. Between 1960 and 1978, China's total GDP and per capita GDP have grown at annual average growth rates of only 5.22% and 3.07% respectively. By contrast, from 1978 to 2012, Chinese GDP has performed a much higher growth rate of 10.16% with an almost tripled GDP per capita growth rate (9.20%). These fast economic growth rates have decupled China's GDP in both aggregate and per capita terms in about three decades. As a result, China surpassed the US becoming the first largest economy in the world in 2014.

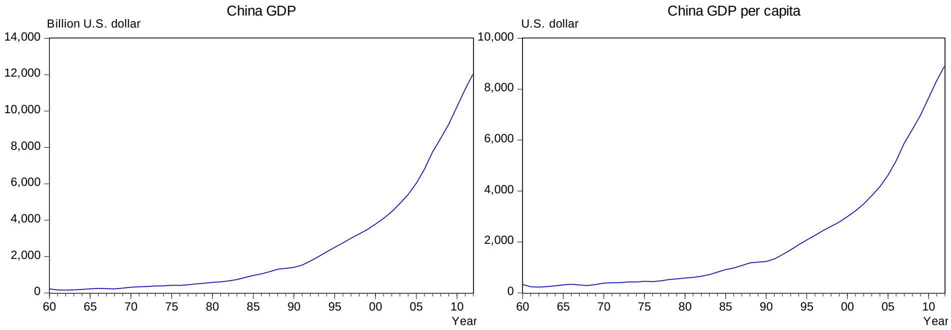

Figure 3.1: China GDP and per capita GDP

GDP per capita values are adjusted by Purchasing Power Parity at the constant 2000 price US dollar. Source: World Bank, World Development Indicator 2014.

Table 3.1: China's GDP and GDP per capita at national level

Year	GDP	GDP growth rate	GDP per capita	GDP per capita growth rate
1960	222.08	-27.10	332.92	-26.36
1970	315.92	7.00	386.06	4.10
1980	577.53	7.80	588.57	6.46
1990	1,403.56	9.20	1,236.41	7.72
2000	3,783.47	8.40	2,996.46	7.55
2010	10,247.34	10.40	7,660.39	9.87
1960-1978	297.42	5.22	361.92	3.07
1978-2012	3,887.49	10.16	3,056.24	9.02

Value of GDP and GDP per capita are adjusted by Purchasing Power Parity in constant 2000 price US dollar[40]. GDP figures are in billions of US dollar (1 billion = 1,000,000,000). Source: World Bank, World Development Indicator 2014.

Although Chinese economy has grown remarkably, it is widely observed that economic disparities exist among Chinese provinces. In the early stage of China's economic reform, Chinese government gave preferential policy treatment to the coastal region such as the establishment of Special Economic Zones (SEZs), granting local government greater independence on international trade activities and special tax incentives to attract foreign investment. Through promoting trade openness and FDI inflow greatly, these preferential policies enabled the coastal region rapid marketization and internationalisation leading to faster economic growth in the coastal provinces than all other provinces.

From 1985 to 2010, per capita GDP has grown spectacularly in all Chinese provinces, but the provincial disparities of GDP per capita have also enlarged (table 3.2

[40] Original GDP, trade and FDI figures are in terms of nominal value, i.e. monetary term in the according year. Changes in the nominal value may due to changes in the real value and/or changes in the associated prices. In order to capture the real value changes and removed the price effect, we convert all our GDP, trade and FDI figures from current nominal value to purchasing power parity adjusted constant price value, so that the effects of inflation and price are removed.

and figure 3.2). As shown in table 3.2, in 1985, except three municipal cities: Beijing, Shanghai and Tianjin, who had much higher per capita GDP level, the GDP per capita values were quite close in the rest provinces, most of which had a per capita GDP level between 10,000 and 50,000 yuan. Although the eastern provinces[41] had slightly higher per capita GDP on average, the difference was not much comparing with central and western provinces. However, after 26 years (1985-2010), the GDP per capita disparities have enlarged significantly. Most of the eastern provinces had a GDP per capita over 30,000 yuan, and particularly all three municipal cities had an over 60,000 yuan GDP per capita. By contrast, the western and central provinces had much lower per capita GDP between 10,000 yuan and 30,000 yuan, except Inner Mongolia who had a per capita GDP over 30,000 yuan (37,776 yuan). Comparatively, provinces in the western region were relatively poorer than central provinces, since provinces with low per capita GDPs such as Guizhou, Gansu and Yunan were in the western region. From table 3.2 and figure 3.3, it can be seen clearly that provinces in the east region were richer over the period 1985-2010, whereas central and western regions had relatively lower GDP values.

[41] The definitions of three geographical zones are not consistent in official and academic publications. We define the Eastern region include 11 provinces and municipalities: Beijing, Fujian, Guangdong, Hainan, Hebei, Jiangsu, Liaoning, Shandong, Shanghai, Tianjin and Zhejiang. The central region includes 8 provinces: Anhui, Heilongjiang, Henan, Hubei, Hunan, Jiangxi, Jilin and Shanxi. The western region includes 12 provinces and municipalities: Chongqing, Gansu, Guangxi, Guizhou, Inner Mongolia, Ningxia, Qinghai, Shaanxi, Sichuan, Tibet, Xinjiang and Yuanan. According to the “Northeast Area Revitalization Plan”, we refer to the Northeast region as three provinces: Liaoning, Jilin and Heilongjiang. Tibet and Taiwan data are missing. Chongqing data are consolidated with Sichuan data.

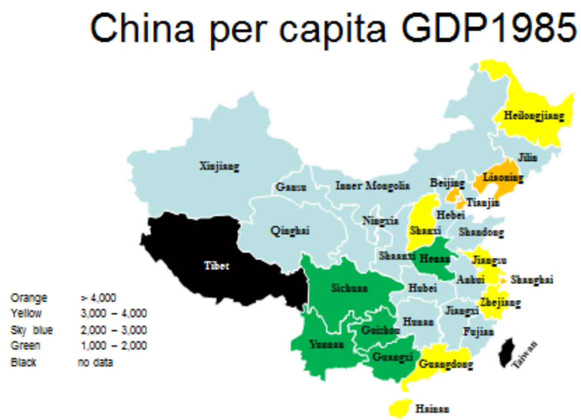

Figure 3.2: China provincial GDP per capita 1985 and 2010
Source: National Bureau of Statistics of China.

Table 3.2: GDP per capita in provinces

Province	GDP 1985	GDP 2010	GDP 1985-2010
Eastern			
Beijing	12,248	64,838	27,298
Fujian	2,544	33,841	11,439
Guangdong	3,598	38,386	14,277
Hainan*	3,162	19,316	7,837
Hebei	2,172	22,936	8,215
Jiangsu	3,734	42,630	13,947
Liaoning	4,870	35,015	12,431
Shandong	2,951	33,413	11,201
Shanghai	16,449	64,565	31,023
Tianjin	7,768	60,455	20,819
Zhejiang	3,869	43,106	15,302
Central			
Anhui	2,291	16,848	5,556
Heilongjiang	3,590	21,656	8,791
Henan	1,728	18,872	6,259
Hubei	2,884	21,829	7,216
Hunan	2,455	19,536	6,541
Jiangxi	2,040	17,491	5,789
Jilin	2,815	25,169	8,359
Shanxi	3,017	21,040	7,388
Western			
Gansu	2,119	12,126	4,609
Guangxi	1,609	16,076	5,342
Guizhou	1,484	10,356	3,483
Inner Mongolia	2,630	37,776	9,884
Ningxia	2,542	20,320	6,605
Qinghai	2,931	16,776	6,289
Shaanxi	2,204	21,557	6,527
Sichuan**	1,988	18,058	6,005
Xinjiang	2,961	19,221	7,822
Yunnan	1,786	12,330	5,078

All GDP figures are in unit of Chinese yuan at the constant price of the year 2000.
GDP 1985-2010: average GDP per capita over the period 1985 – 2010.
Data for Tibet and Taiwan are missing.
*Hainan**: Hainan was part of Guangdong province and became a province in 1988, so there is no data available for Hainan province before 1987. Instead of the year 1985, we use the Hainan data of the year 1987, which is the earliest data point available for Hainan province from National Bureau of Statistics of China (NBSC).*
*Sichuan**: Chongqing was a part of Sichuan province and given municipality directly under the jurisdiction of central government in 1996, so there is no separate data for Chongqing before 1996. For consistency, Chongqing data are consolidated with Sichuan data.*
Source: National Bureau of Statistics of China.

3.3.2 China's trade openness

As discussed by many academic studies as well as mass media, China's success in economic growth is undoubtedly contributed by its international trade and FDI inflows. Before 1978, Chinese government adopted the central planned economy and inward-oriented policy with the aim of establishing state-own industries in order to foster national economic growth. Thus, China had little trade with the outside world. China's main imports were strategic materials and some necessities, which were not available in the domestic market. China's main exports were raw surplus materials and simple manufacturing products with the aim of covering China's imports payments. These conservative policies did protect the domestic industries, but at the same time led to less efficient resource allocation in Chinese economy. Meanwhile this import substitution policy restricted China's trade with other countries causing Chinese industries lack of competition, low level of productivities and unable to enjoy dynamic benefit from international trade, such as competition effect, efficiency effect and technology effect (Brandt and Rawski, 2008).

Since 1978, the on-going economic reform has successfully converted China from an inward-oriented country to an outward-oriented one, transforming China from a close economy to an open market with greater dependence on international trade. Chinese government has adopted the so called "open door" policy introducing series of policies to encourage international trade, such as cancelling import substitution list, cutting tariff rate and reducing non-tariff barriers. For instance, China's tariff rate has been cut massively from 56% (1982) to 15% (2001), and reduced further to only 9.8% (2008) after China's accession to the World Trade Organisation (WTO) (Zhang, 2014). Since then, China has been gradually opening up her economy from coastal area to inland, integrating into the global trade system and enjoying tremendous benefits from the international trade (Koopman et al., 2008).

As a result, China's trade openness has distinctly soared up from less than 10% to over 50% of China's total GDP (figure 3.3), though with some cutbacks such as 1994-1996 and 2008[42], still making China the largest exporter and second largest importer in the world in 2013 (Morrison, 2014). From 1998 to 2012 (table 3.3), China's exports and

[42] A significant cutback of China trade openness in the period 1994-1996, may be because China reformed the exchange rate system combining the RMB exchange rates, adopting the bank exchange settlement system and setting up a unified inter-bank foreign exchange market. On this basis, China included the foreign exchange business of the foreign-invested enterprises in the bank's exchange settlement system in 1996. As a result, Chinese yuan has strengthened steadily from 8.7 (1994) to the dollar to around 8.28 (1996). Another significant cutback in 2008 is due to of the global financial crisis (Marelli and Signorelli, 2011, Tian and Yu, 2012)

imports have climbed up by about 7 times, from 440 and 335 billion to around 3 and 2.7 trillion US dollar. Table 3.3 also tells that both China's exports and imports increased siginificantly after China's accession to the WTO. Rise in China's trade volumn indicates that the revision of Chinese government's policies for meeting China's commitment to the WTO created great incentives to facilitating China's international trade. It may also worth notice that China's trade openness ratio fell after 2006, and the absolute term China's trade volume dropped significantly after the 2008. This is due to the global financial crisis in 2007-2008.

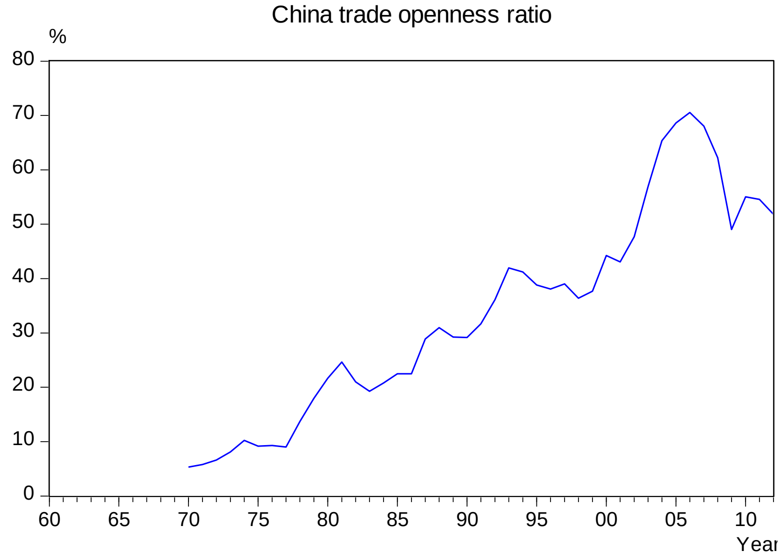

Figure 3.3: China's trade openness
Source: World Bank, World Development Indicator 2014.

Table 3.3: China's trade volume, exports and imports

Year	Trade	Exports	Imports
1998	776.22	440.30	335.92
1999	874.83	472.87	401.96
2000	1,127.30	592.31	534.99
2001	1,187.25	619.88	567.38
2002	1,437.35	753.89	683.46
2003	1,920.27	988.88	931.39
2004	2,436.78	1,252.30	1,184.48
2005	2,887.62	1,547.40	1,340.22
2006	3,444.59	1,895.98	1,548.62
2007	3,952.86	2,214.55	1,738.31
2008	4,324.14	2,413.54	1,910.60
2009	3,746.22	2,039.19	1,707.03
2010	4,732.24	2,511.70	2,220.54
2011	5,364.86	2,801.17	2,563.69
2012	5,594.71	2,968.77	2,625.95

Values of trade volume, exports and imports are adjusted by the Purchasing Power Parity in constant 2000 price US dollar. Trade volume, exports and imports figures are in billions of US dollar (1 billion = 1,000,000,000). Source: National Bureau of Statistics of China.

At provincial level, there are clear regional disparities in trade openness. As shown in figure 3.4, in early stage of China’s economic reform (1985), though some coastal provinces such as Guangdong and Liaoning had obviously greater trade openness, generally most Chinese provinces had relatively similar level of trade openness. Most of Chinese provinces had trade openness ratios less than 10%. However, after 26 year in 2010, all provinces in coastal region had much larger trade openness than inland provinces. All coastal provinces had trade openness ratios over 30%, whereas trade openness ratios in most inland provinces were still in the range of 10%-20%. Over the period 1985 to 2010, coastal provinces general have on average 20-30% higher trade openness ratio than inland provinces.

It is easy to understand that coastal provinces have much higher trade openness ratios, since coastal provinces have better geographic location for trade, and also Chinese government establishes Special Economic Zones (SEZs) in the coastal provinces and gives preferential policies to coastal region. Thus the coastal provinces are opened up earlier for trade and foreign investment, and have much more exports and imports than inland provinces. This imbalanced geographic distribution of trade may also be seen in figure 3.5. Moreover, figure 3.5 also tells us that the levels of trade openness in inland provinces have not changed much, but they have significantly increased in coastal provinces over the past 26 years. Over the period 1985-2010, eastern provinces not only have higher trade openness ratios, but also have experienced significant increasing trend in trade openness ratios. Whereas, inland provinces have lower trade openness ratios as well as relatively flatter trade openness levels over the past 26 years.

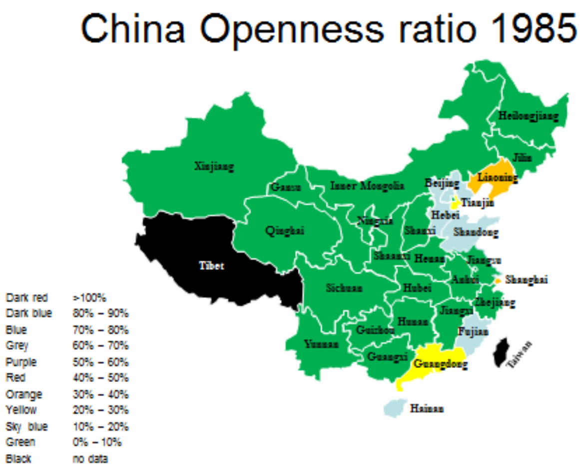

Figure 3.4: China provincial trade openness 1985, 2010, and average of 1985-2010
Source: National Bureau of Statistics of China.

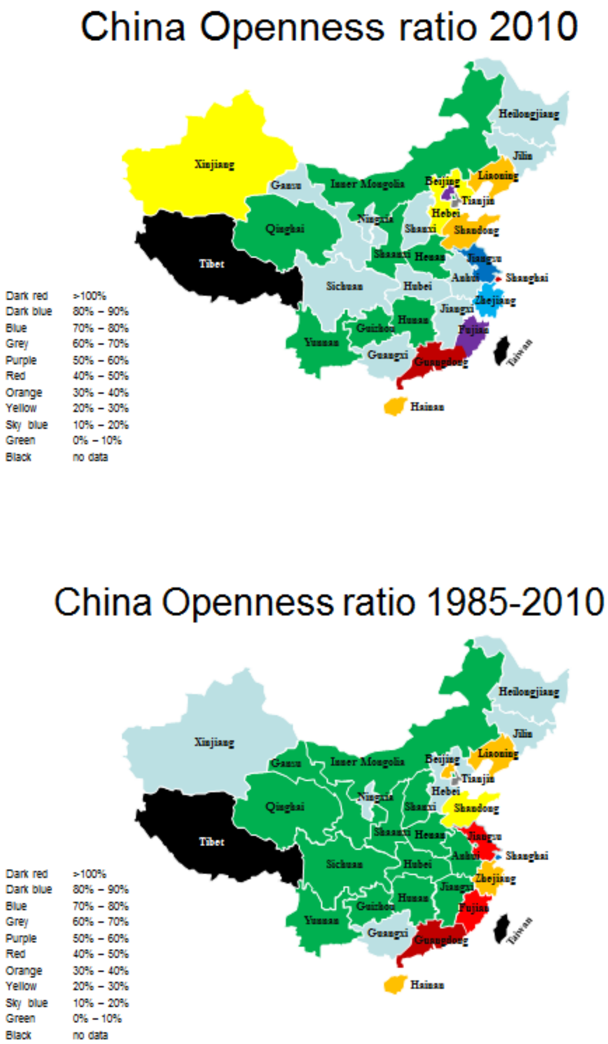

Figure 3.4: China provincial trade openness 1985, 2010, and average of 1985-2010 (continues)

Source: National Bureau of Statistics of China.

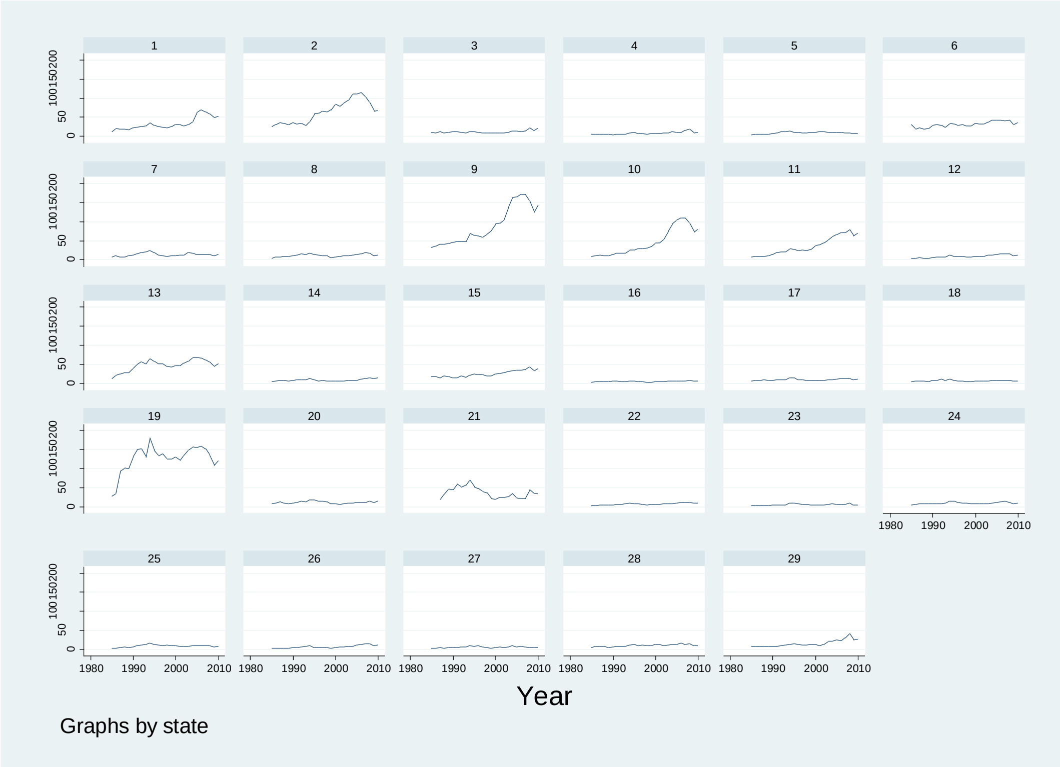

Figure 3.5: Trade openness by province
Y-axis: trade openness ratio (exports plus imports divided by GDP) in percentage. X-axis: year. Source: National Bureau of Statistics of China.

Province code

Province/city	Code	Province/city	Code
Beijing	01	Henan	16
Tianjin	02	Hubei	17
Hebei	03	Hunan	18
Shanxi	04	Guangdong	19
Inner Mongolia	05	Guangxi	20
Liaoning	06	Hainan	21
Jilin	07	Sichuan	22
Heilongjiang	08	Guizhou	23
Shanghai	09	Yunnan	24
Jiangsu	10	Shaanxi	25
Zhejiang	11	Gansu	26
Anhui	12	Qinghai	27
Fujian	13	Ningxia	28
Jiangxi	14	Xinjiang	29
Shandong	15		

3.3.3 China's FDI inflows

Not only trade openness, but also foreign investment. Before China's economic reform, capital flows from capitalist countries were explicitly rejected due to the nationalistic and ideological reason (Wu, 1984). In 1979, Chinese government adopted the "Law of the People's Republic of China on Joint Ventures Using Chinese and Foreign Investment", giving the foreign investment a legal status in China. The attitude towards foreign investment changed. Since then, foreign investment has begun entering China and grown steadily. Between 1980s and 2010s, it has been seen massive flows of foreign direct investment (FDI) participating in Chinese economy. According to data from the National Bureau of Statistics of China (NBSC), annual actual used FDI have risen sharply by over 20 times in three decades (1983-2012), from just over 7 billion US dollar in 1983 to about 162 billion US dollar in 2012; meanwhile total FDI stock have grown even more dramatically from just around 8.5 billion US dollar in 1980 to over 1.2 trillion US dollar in 2012, which is about 142 times larger (figure 3.6). By 2012, China has become the largest FDI recipient country attracting 18% of world total FDI inflows, 6% higher the second place nation, the US (Davies, 2013, and OECD, 2013).

As shown in figure 3.6 and table 3.4 as well as discussed in many academic papers (Kamath, 1990, Chen et al., 1995, OECD, 2000, Brandt and Rawski, 2008, and Zhang, 2014), generally the trend of FDI inflows into China may be divided into four stages: experimental (steady) growth stage (1979-1991), peak stage (1992-1994), adjustment stage (1995-2000) and the renascent/recovery stage (2001 onwards).

At the early stage of China's economic reform (1979-1983), Chinese government adopted an experimental approach towards foreign investment. Chinese government introduced series of FDI policies, including *Law of the People's Republic of China on Joint Ventures Using Chinese and Foreign Investment (Law of Joint Ventures, 1979), Law of the People's Republic of China on the Income Tax of the China-Foreign Joint Ventures (1980), Law of Foreign Enterprise Income Tax (1981), Act on the Implementation of the Law on Joint Ventures (1983)*. These early policies provided legal clearance, introduced incentives and set up basic formwork for foreign investment (National People's Congress in 1979). In 1986, wholly foreign-own enterprises were permitted to enter the Chinese market. Numbers of new policies were introduced by the Chinese government to facilitate FDI inflows, including *Law on Enterprises Operated Exclusively with Foreign Capital (1986), Provisions of the State Council of the People's Republic of China for the Encouragement of Foreign Investment (1986), Notice for Further Improvement in the Conditions for the Operation of Foreign Invested*

Enterprises (1986), Provision for the FDI Encouragement (1986), Constitutional Status of Foreign invested Enterprises in Chinese Civil Law (1986), Adoption of Interim provision on guiding FDI (1987), Detailed Rules and Regulations for the Implementation of the People's Republic of China Concerning Joint Ventures with Chinese and Foreign (1990). These legal legislations provided further clearance, created legislative framework and introduced more incentives for FDI, and at the same time, improved investment climate and business environment for foreign investment coming into China (Jia, 1994, Potter, 1995, Chen, 2011 and Davies, 2013). As a result, FDI inflows and FDI projects were growing steadily from 1979-1991, annual amount of inflows and projects were still quite low at the level between 10 and 20 billion US dollar for less than 8,000 projects (table 3.4).

China's FDI inflows shot up to a peak stage from 1992 to 1994 (stage 2). This FDI inflows spurt was widely believed due to the strong push by China's then leader, Deng Xiaoping's famous circuit in the south coastal region in the spring of 1992, which further imphasised China's commitment to market-oriented economic reform and open door policy, at the same time gave more confidence to foreign investors. Immediately, FDI inflows performed a 132% growth from about 19 billion to 44.6 billion in 1992, and repeated a sharp growth again in the following year. In 1994, the annual FDI inflows into China reached a peak point of 98.54 billion. Accordingly, as the FDI inflows rose largely, the number of FDI projects also climbed to a peak of 83,437 in 1993 (figure, 3.6 and table 3.4).

For promoting more efficient utilisation of the foreign investment, Chinese government issued the *Provisional Guidelines for Foreign Investment Projects* (National People's Congress) in 1995. The introduction of this document was of two aims. On the one hand, this document opened more Chinese sectors for foreign investment. Opened sectors included agriculture, energy, transportation, basic raw materials and high-technology among others. On the other hand, this document also symbolled the start of Chinese government's guidance on FDI inflows to meet China's own economic development target. In this document, FDI projects were categorised into types: encouraged, permitted, restricted and prohibited. The "encouraged" FDI projects referred to those either export-oriented, with advanced technology, manufacturing new equipment/materials to satisfy market demand, in infrastructure, or in underdeveloped agriculture. If an FDI project was engaged in the exploration of rare and valuable mineral resource, in some sectors that were under experiment or monopolised by the nation, involving production with exceeded market demand, or with low level of technology, then this FDI project should be "restricted". When an FDI project was classified to be "prohibited", then it must be jeopardized for national security, harmful for the public interest, damaging the natural environment, natural resource or human health, or using a sizable amount of arable land. Any project that did not belong to either group of the above was classified as the "permitted" project. Thus in this third stage (1995-2000), Chinese government has slightly adjusted its policies for attracting not only more but better quality of FDI inflows. As a result, numbers of FDI projects have plummeted and grown at a negative rate. Meanwhile, FDI inflows have also grown at a low level, and annual FDI inflows have flatted at about 100 billion (figure, 3.6).

Accession to the World Trade Organisation (WTO) opened a new chapter for China's FDI inflows in the early 2000s. China began to revise her regulations to meet her WTO commitments. To name a few, China's policy revision included reducing tariff rate for international trade, eliminating various barriers on FDI inflows, opening up and lifting restriction in some key sectors, and abandoning discriminating treatment to foreign banks. These policy changes have significantly encouraged FDI inflows, especially FDI inflows into exported-oriented sectors, tertiary sectors and financial sectors have led to economic growth. As a result, China annual FDI inflows have performed rapid rising trend and China has surpassed the US becoming the largest FDI recipient country in the world in 2012.

Although the trend of FDI inflows into China have experienced few fluctuations over the past three decades, FDI inflows are believed to be significantly contributing to China's rapid economic growth, thus it is not surprising to see that China's GDP growth is positively related to FDI inflows. Despite enormous amounts of FDI inflows have entered China and been generally increasing on a growing trend, there are significant imbalances in the geographical distribution of China's FDI inflows.

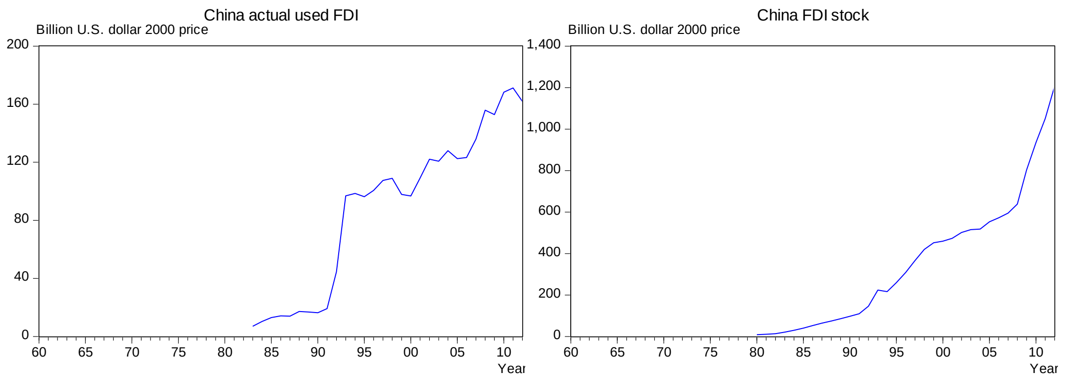

Figure 3.6: China's actual used FDI and FDI stock
Source: National Bureau of Statistics of China and United Nations Conference on Trade and Development (UNCTAD) http://unctad.org/en/Pages/Home.aspx *[Accessed 28/02/2014].*

Table 3.4: China FDI inflows 1979-2012

Year	Number of project	Growth rate of project (%)	Actual used FDI	Actual used FDI growth rate (%)
1979-1982	922		9.06	
1983	470		7.07	
1984	1856	294.89	10.40	47.09
1985	3073	65.57	13.00	24.99
1986	1498	-51.25	14.23	9.52
1987	2233	49.07	13.96	-1.94
1988	5945	166.23	17.19	23.15
1989	5779	-2.79	16.82	-2.13
1990	7273	25.85	16.34	-2.87
1991	12978	78.44	19.15	17.18
1992	48764	275.74	44.60	132.94
1993	83437	71.10	96.85	117.12
1994	47549	-43.01	98.54	1.75
1995	37011	-22.16	96.28	-2.30
1996	24556	-33.65	100.59	4.48
1997	21001	-14.48	107.48	6.85
1998	19799	-5.72	108.90	1.33
1999	16918	-14.55	97.81	-10.19
2000	22347	32.09	96.77	-1.06
2001	26140	16.97	109.18	12.82
2002	34171	30.72	122.13	11.86
2003	41081	20.22	120.74	-1.14
2004	43664	6.29	127.97	5.99
2005	44001	0.77	122.51	-4.27
2006	41473	-5.75	123.32	0.66
2007	37871	-8.69	135.97	10.26
2008	27514	-27.35	155.87	14.64
2009	23435	-14.83	152.79	-1.97
2010	27406	16.94	168.19	10.08
2011	27712	1.12	171.18	1.78
2012	24925	-10.06	161.89	-5.43

The number of project refers to the project numbers of the enterprises with foreign investment.
Values of actual used FDI are adjusted by the Purchasing Power Parity in constant 2000 price US dollar. FDI inflows figures are in billions of US dollar (1 billion = 1,000,000,000).
Growth rates are in percentage.
Source: National Bureau of Statistics of China.

Similar to trade openness, FDI inflows to China also show significant geographical unbalance patterns. Because of Chinese government's preferential policies, the east region claimed lion amount of FDI inflows between 1985 and 2009 (table 3.5). At the beginning of China's economic reform, Chinese government experimentally established special economic zones (SEZs) in four coastal cities, in early 1980s. They were Shantou, Shenzhen and Zhuhai in Guangdong province and Xiamen in Fujian province. Due to their special geographical location – Shenzhen and Zhuhai are adjacent to Hong Kong and Macao, while Shantou and Xiamen are both facing Taiwan over the strait, these early SEZs were designed with the intention of absorbing and utilising foreign capital and advanced technology as well as facilitating investment from Hong Kong, Macao and Taiwan. With the satisfactory economic situation in these four SEZs as well as the whole country, China further opened fourteen coastal cities[43] and an entire province, Hainan[44] for overseas investment in 1984. Shortly afterwards, open economic zones have extended into several provinces on the coast forming the so called "open coast belt" in the early 1990s. These SEZs were given preferential policies such as tax concessions and privileges, whereas foreign investment in other Chinese regions was still limited. Particularly, FDI inflows were highly concentrated in Guangdong, Jiangsu, Liaoning, Shanghai, Zhejiang and Fujian. Even after Chinese government adopted preferential policies to inland provinces such as the "Great Western Development Strategy" and the "Northeast Area Revitalization Plan", FDI inflows to inland provinces have increased but still relatively a lot less than the eastern provinces. However, in terms of FDI inflows share, it has been seen a significant rise in inland province, whereas the share of eastern region has been reducing over time from 84.85% (1985) to 74.19% (2009).

Although FDI inflows to all Chinese provinces have been dramatically increasing, FDI inflow to GDP ratio have been in fact reducing in most of provinces over the period 1985-2009 (figure 3.7). Instead of showing FDI inflows becoming less important, the reducing FDI inflows to GDP ratios may actually tell us that the GDP values have grown much faster than the FDI inflows in most Chinese provinces. In contrary to the increasing trade openness ratio in most Chinese provinces, international trade measured by FDI inflow to GDP ratio may tell a different story, since FDI inflow to GDP ratios

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[43] These fourteen cities are Dalian (Liaoning province), Qinhuangdao (Heibei province), Tianjin (municipality), Yantai (Shandong province), Qingdao (Shandong province), Lianyungang (Jiangsu province), Nantong (Jiangsu province), Shanghai (municipality), Ningbo (Zhejiang province), Wenzhou (Zhejiang province), Fuzhou (Fujian province), Guangzhou (Guangdong province), Zhanjiang (Guangdong province) and Beihai (Guangxi province).

[44] At that time, Hainan was still a city in Guangdong province, and became a province in 1988.

may go opposite direction of trade openness ratios. Comparing figure 3.7 with figure 3.6, it can be seen that trade openness ratios have been rising in most eastern provinces, but FDI to GDP ratios have kept quite flat as in Beijing, Tianjin, Shanghai, Jiangsu and Zhejiang, or even declined as in Fujian, Guangdong and Hainan, in the coastal provinces over the period 1985-2009. Therefore it should be caution when utilising trade openness ratio and FDI inflow to GDP ratio as measures of China's international trade.

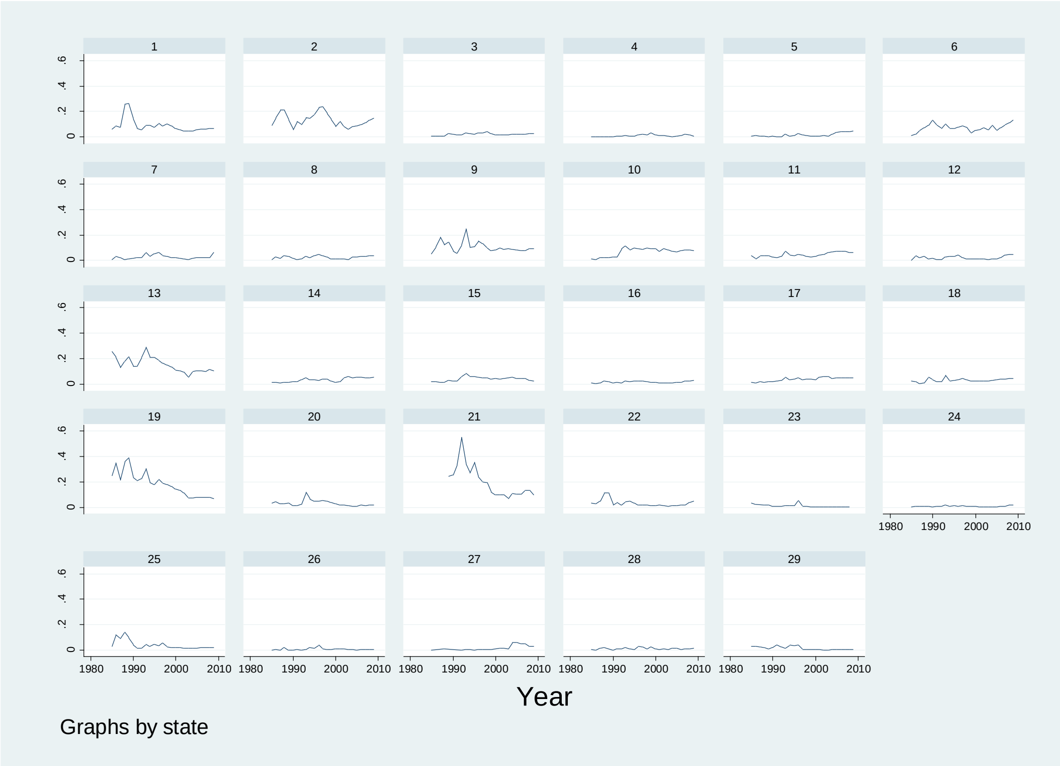

Figure 3.7: FDI to GDP ratio by province
Source: National Bureau of Statistics of China.

Province code

Province/city	Code	Province/city	Code
Beijing	01	Henan	16
Tianjin	02	Hubei	17
Hebei	03	Hunan	18
Shanxi	04	Guangdong	19
Inner Mongolia	05	Guangxi	20
Liaoning	06	Hainan	21
Jilin	07	Sichuan	22
Heilongjiang	08	Guizhou	23
Shanghai	09	Yunnan	24
Jiangsu	10	Shaanxi	25
Zhejiang	11	Gansu	26
Anhui	12	Qinghai	27
Fujian	13	Ningxia	28
Jiangxi	14	Xinjiang	29
Shandong	15		

Table 3.5: FDI inflows by province

Province	FDI 1985	FDI/GDP 1985	FDI 2009	FDI/GDP 2009
Eastern	**1121.49**		**12861.89**	
Beijing	72.69	0.29	711.85	0.06
Fujian	177.58	0.89	1108.61	0.09
Guangdong	506.92	0.88	2369.13	0.06
Hainan	46.00	0.51	129.26	0.08
Hebei	7.21	0.02	393.86	0.02
Jiangsu	29.74	0.05	2265.38	0.07
Liaoning	21.42	0.04	1759.92	0.12
Shandong	39.11	0.06	719.73	0.02
Shanghai	105.05	0.23	1236.57	0.08
Tianjin	56.81	0.33	953.61	0.13
Zhejiang	58.97	0.14	1213.96	0.05
Central	**79.43**		**2872.94**	
Anhui	3.73	0.01	391.56	0.04
Heilongjiang	7.68	0.02	264.02	0.03
Henan	7.25	0.02	445.12	0.02
Hubei	15.61	0.04	517.59	0.04
Hunan	31.43	0.09	461.45	0.04
Jiangxi	9.10	0.04	344.59	0.05
Jilin	4.40	0.02	403.65	0.06
Shanxi	0.24	0.00	44.97	0.01
Western	**120.84**		**1601.29**	
Gansu	0.52	0.00	17.74	0.01
Guangxi	21.51	0.12	109.13	0.01
Guizhou***	13.70	0.11	14.88	0.00
Inner Mongolia	1.93	0.01	352.97	0.04
Ningxia	0.36	0.01	15.93	0.01
Qinghai	0.10	0.00	22.99	0.02
Shaanxi	20.14	0.11	134.49	0.02
Sichuan**	50.00	0.12	811.07	0.04
Xinjiang	11.10	0.10	22.41	0.01
Yunnan	1.48	0.01	99.70	0.02

All FDI figures are in million of Chinese yuan at the constant price of the year 2000.
FDI/GDP figures are in percentage.
Data for Tibet and Taiwan are missing.
Hainan: Hainan was part of Guangdong province and became a province in 1988, so there is no data available for Hainan province before 1987. Instead of the year 1985, we use the Hainan data of the year 1989, which is the earliest data point available for Hainan province from National Bureau of Statistics of China (NBSC).*
*Sichuan**: Chongqing was a part of Sichuan province and given municipality directly under the jurisdiction of central government in 1996, so there is no separate data for Chongqing before 1996. For consistency, Chongqing data are consolidated with Sichuan data.*
*Guizhou***: FDI inflows value in 2009 is missing, so we use FDI inflows in 2008 instead.*
Source: National Bureau of Statistics of China.

3.3.4 China's environmental issues

Nowadays, one hot topic about the environment is China's environmental issue. According to the World Bank (2013), 20 of the world's 30 most polluted cities are in China, and dozens of Chinese cities are classified as severe polluted. Many major cities including Beijing and Shanghai have to experience heavily smog days many times a year. It becomes more often to see that smog stretches hundreds of miles around Chinese cities, and "toxic gray shroud" constantly covers massive area of the country. Acid rain is falling on one third of the country and one third of the urban population is breathing polluted air. Severe air pollution is threatening Chinese people's health. As reported by Chinese Ministry of Health, the ambient air pollution alone kills hundreds of citizens very year; 350,000 to 400,000 premature deaths are due to high pollution levels in cities and another 300,000 deaths are due to poor indoor air quality (Kahn and Yardley, 2007). Not only air pollution is serious problem for China, but also water pollution. On the one hand, China's water resources are overused due to China's rapid economic growth and large population burden. On the other hand, most of China's water resources are polluted by production and consumption wastes. The combination effects of these two sides cause serious water shortage as well as water pollution problems in China. 400 out of 600 Chinese cities are facing water shortages to various degrees, including 30 out of 32 major cities (Piao et al., 2010). Only 11.85% of China total water resources are graded good quality, over 70% of China's water resources are polluted, more than 60% rivers and lakes suffer from pollution to such an extent that they cannot be safely used as drinking water resources, and almost 90% of underground water in cities is affected by pollution (Hong, 2006). The health of Chinese people is also threatened by China's water pollution. According to the World Bank report (World Bank, 2014), more than 20 million Chinese are living under the threat of Arsenic poisoning and over 60,000 premature deaths are closely related to water pollution every year.

Although it is certainly that China's environmental degradation problem is not a recent phenomenon that only stems from China's economic reform and opening-up process, it is evident that China's rapid economic growth and integration to world economy have in deed significantly aggravated China's natural environment. As shown in figure 3.8 and 3.9, after the economic reform in the late 1970s, both China's SO_2 and CO_2 emissions have experienced sharp rises, and further soared up unprecedentedly since China's accession to the WTO in the early 2000s. It can be seen obviously that the historical trends of China's SO_2 and CO_2 emissions are closely associated with China's rapid economic growth and growing liberalisation in trade and foreign investment. These historical trends of China's SO_2 and CO_2 emissions are two typical pollution indicators exhibiting an image that China's success in economic development seems at the cost of environment degradation.

Among all sources of pollution, industrial pollution is a primary source of environmental problems in China. According to Ministry of Environmental Protection report (MEP, 2012), large shares of air and water pollution are from industrial activities. Over 80% of air pollution is from industrial sector, including 83.9% of SO_2 emissions and 80.9% of flue dust. In the case of water pollution, industrial water pollution accounts 45.8% of China's total water pollution, producing 38.1% Chemical Oxygen Demand (COD) and 31.7% Ammonia and Nitrogen (Zhang, 2014).

Three major industrial pollutants are waste gas, waste water and solid waste. Figure 3.10, 3.11 and 3.12 provide some insights about China's waste gas, waste water and solid waste discharge over the period 1985-2010. It sees that waste gas and solid waste emissions share a similar exponential growing trend, whereas waste water discharge first reduces from 25 billion tons to around 18 billion tons in the late 1990s, and bounces back to about 25 billion tons. Moreover, these trends of waste gas, waste water and solid waste are not only found in aggregate level but also in per capita term. Particularly, per capita waste water also follows a U shape curve as aggregate waste water, but it falls to around 15 tons between late 1990s and early 2000s, and then goes up again back to about 19 tons in the late 2000s. This U shape curve of China's waste water may be due to the interaction of government's policies as well as dirty industries development. The fall of waste water between late 1980s and late 1990s may be due to several water resource regulations introduced by Chinese government in this period, such as the "Law of the People's Republic of China on the Prevention and Control of Water Pollution" (1984) and the "Water Law of the People's Republic of China" (1988); whereas the rebound in 2000s may be because of a scale effect as proposed by Xiao et al. (2006). In a study of China's industrial waste water discharge in the period 1991-2004, Xiao et al. (2006) finds that though China's waste water intensity has been continuously reducing, the total output from papermaking enterprises have actually scaled up distinctly, resulting a significant rise in total amount of waste water discharge in the 2000s. In contrary to aggregate and per capita terms of these three pollutants, the intensities of them have all been extensively falling over time from 1985 to 2010.

Similar to China's economic growth and international trade, it can be seen that China's industrial pollution also shows imbalanced geographical distribution. However, as shown in figure 3.13, 3.14 and 3.15, these regional disparities in industrial pollution seem to be not consistent with economic growth and international trade. From 1985 to 2010, per capita waste gas and solid waste in most provinces have increased significantly, but almost all provinces have experienced a decline in waste water pollution. Geographically, north provinces have generally higher levels of waste gas and solid waste than the south provinces, but less water waste pollution. It can be seen obviously that provinces in east coast have discharged relatively more waste water. Particularly, as aforementioned, coastal provinces have begun economic reform and been opened up for trade and foreign investment earlier, thus they are relatively more developed regions with higher income levels. However, it is not clear that the fast economic growth and great international trade in these coastal provinces are raising their industrial pollution levels, because high levels of all three pollutants can be found in provinces with higher income level and trade openness ratio as well as in those with lower income level and trade openness ratio.

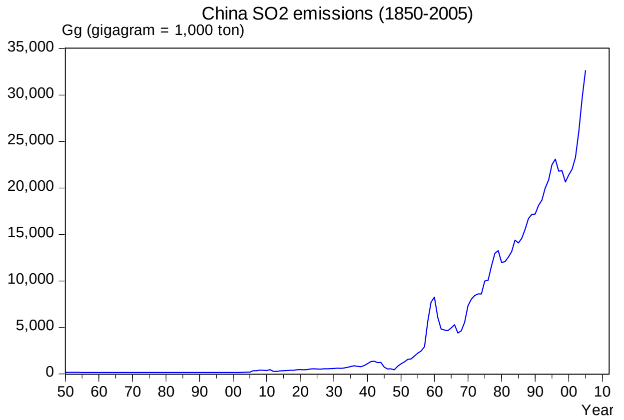

Figure 3.8: China national total SO_2 emissions 1850-2005
Source: Socioeconomic Data and Applications Center (SEDAC)
http://sedac.ciesin.columbia.edu/data/set/haso2-anthro-sulfur-dioxide-emissions-1850-2005-v2-86
[Accessed 06/03/2014]

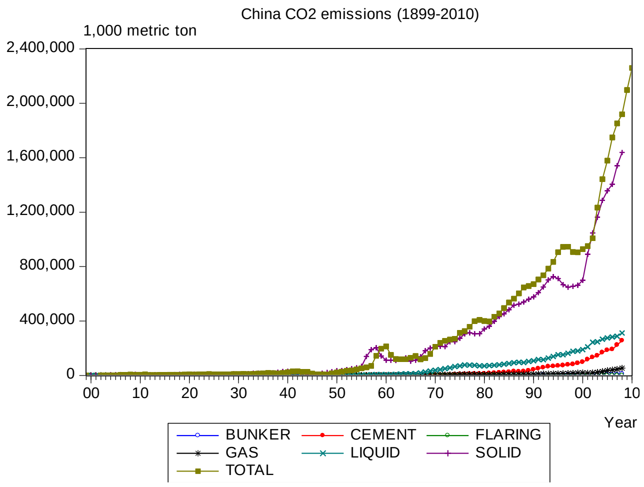

Figure 3.9: China national total CO_2 emissions 1899-2010
Source: Carbon Dioxide Information Analysis Centre (CDIAC) http://cdiac.esd.ornl.gov/ [Accessed 06/03/2014]

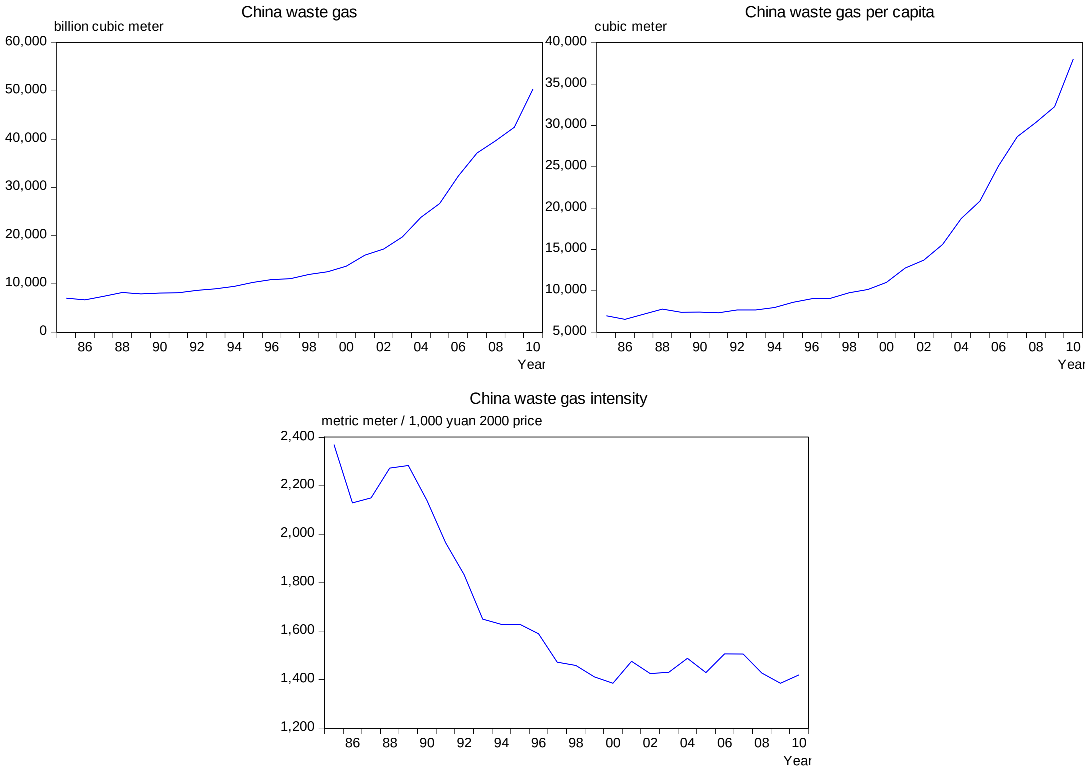

Figure 3.10: China waste gas
Source: National Bureau of Statistics of China.

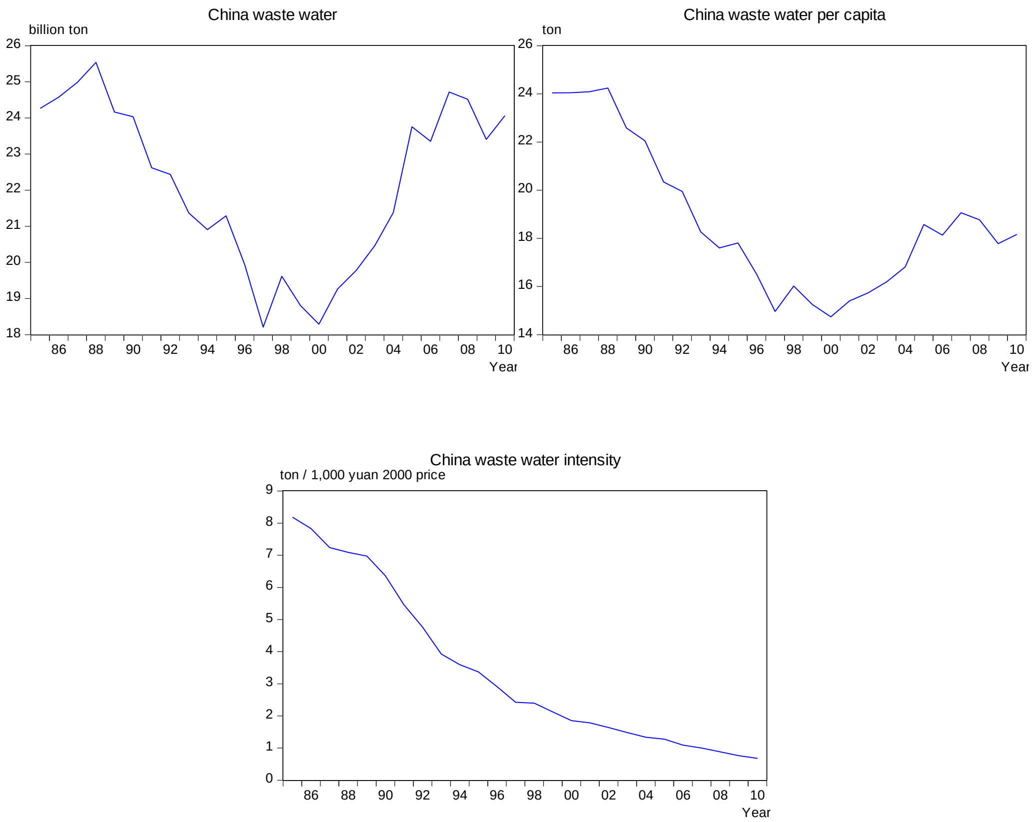

Figure 3.11: China waste water
Source: National Bureau of Statistics of China.

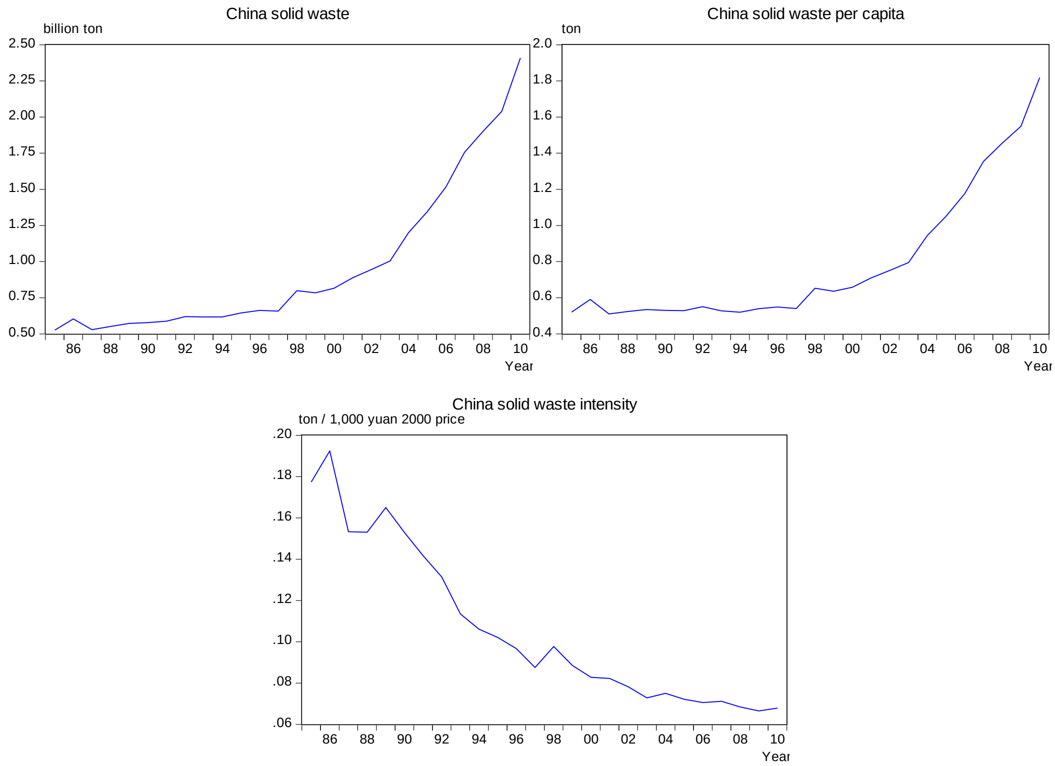

Figure 3.12: China solid waste
Source: National Bureau of Statistics of China.

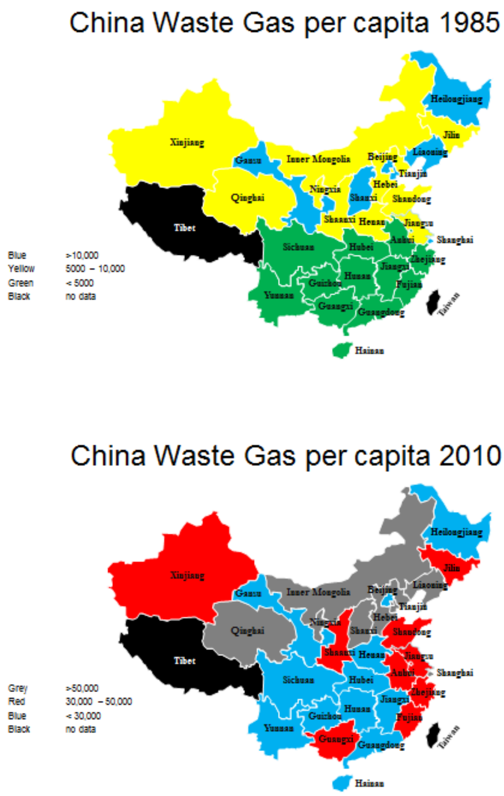

Figure 3.13: China waste gas per capita (cubic meter) in 1985 and 2010
Source: National Bureau of Statistics of China.

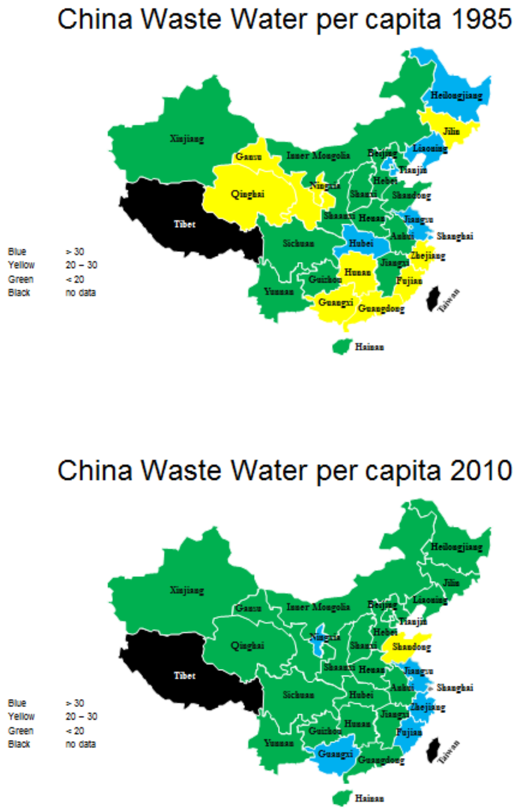

Figure 3.14: China waste water per capita (ton) in 1985 and 2010
Source: National Bureau of Statistics of China.

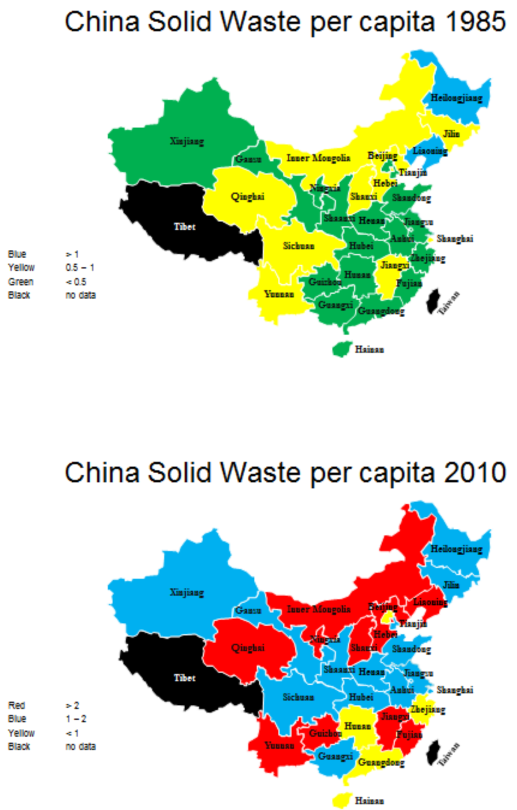

Figure 3.15: China solid waste per capita (ton) in 1985 and 2010
Source: National Bureau of Statistics of China.

3.3.5 China's environmental policies

China's severe environmental problems have attracted much attention on its environmental policies. Contrary to the prevailing wisdom, China started paying attention to her environmental issues even before her economic reform. As early as in the first international environmental conference, China sent a delegation to attend the United Nations Conference on the Human Environment in Stockholm in 1972. Soon after that in 1974, Chinese government established the first national environmental protection bureau, the "Environmental Protection Leadership Group", which gradually evolved into today's "Ministry of Environmental Protection" (MEP), a cabinet-level ministry in the executive branch of the Chinese Government. In the following years, environmental regulation bureaus have been established at various local levels. Until now China has a four-tier environmental protection management system, vertically implementing from national, provincial, municipal to county levels (Zhang, 2014).

With respect to the environmental laws and regulations, basing on the "Constitution of the People's Republic of China", China established her first law on environmental issues in 1979, the "Environment Protect Law" (EPL). The EPL introduces Chinese government's basic principle on protecting the environment, provides guideline for supervision and management of the environment in local governments, and imposes criminal responsibility for serious environmental pollution. Following the EPL, dozens of environmental protection laws have been issued for China's natural resources and environmental pollution. Laws for nature resources include *Forestry Law of the People's Republic of China (1984), Grassland Law of the People's Republic of China (1985), Mineral Resources Law of the People's Republic of China (1986), Water Law of the People's Republic of China (1988) and Law of the People's Republic of China on the Protection of Wildlife (1988),* whereas laws for environmental pollution include *Law of the People's Republic of China on the Prevention and Control of Water Pollution (1984), Law of the People's Republic of China on the Prevention and Control of Environmental Pollution by Solid Waste (1995) and Law of the People's Republic of China on the Prevention and Control of Atmospheric Pollution (2000).* These laws introduce Chinese government's policies on rational utilisation and protection of natural resources, as well as provide guidelines and set up regulation standards for preventing and controlling pollution and other public hazards. Furthermore, although there is no obvious separate environmental standard for foreign investment, foreign investors are requested to follow China's domestic environmental laws, regulations and standards. On top of these, as mentioned in the FDI section, Chinese government issues particular regulations for foreign investment, such as the *Provisional Guidelines for Foreign Investment Projects.* These regulations express clearly Chinese government's policies to attract more environmental friendly foreign investment, but limit or prohibit foreign investment for polluting activities. By 2005, China has issued more than 660 environmental regulations, over 800 national environmental standards and over 30 local environmental standards (Zhang, 2014). Thus, China now has, on paper, the most enlightened set of laws on protecting the environment of any developing nation (MacBean, 2007).

Not only pollution regulations, but also abatement investment, China has invested great amount of money for pollution abatement every year. And China's pollution abatement investment has been increasing over the past three decades. For instance, in 2004, China invested in total about 191 billion yuan, accounting 1.40% of her total GDP in pollution abatement. Among this investment, 114.1 billion (59.8%) was used for city environmental infrastructural construction, and 30.8 billion (16.1%) was used for industrial pollution treatment. From 1987 to 2004, China's investment in industrial pollution treatment has grown more than eight times from less than 4 billion to 30.8 billion yuan (Zhang, 2014).

Despite China's comprehensive environmental regulatory framework and sophisticated environmental legislations, the implementation power is often questioned. The weak enforcement of China's environmental laws and regulations may be due to possible reasons as follows. Firstly of all, China's public awareness of environmental protection and participation in social supervision is still weak (detail discussions are provided in China Council for International Cooperation on Environment and Development (CCICED) report 2013, and Zhang, 2014). Secondly, environmental authorities in China have only limited administrative power. At central government level, although ideally the MEP is in charge of implementing environmental policies, enforcing environmental laws and regulations, funding and organising research and development in environmental domain, it has only limited administrative power and less muscle to punish law-breaking polluters. Whereas, at local level, current legislation only allows local environmental authorities to make suggestions and issue fines, but do not have the power to force a polluting enterprise to make changes within a certain time limit. Since the fines are small in most provinces, it may happen that paying fines cost less than obeying environmental laws and regulations. Thirdly, not only weak administrative power, but also poor coordination between environmental authorities may lead to weak implementation on pollution. Like in many other countries, China's environmental policies are established by central government, overseen by different levels of environmental authorities, and implemented by various government departments. Therefore good coordination between environmental authorities and other government departments determines the implementation power of China's environmental policies. However, due to the lack of legislative clarities of role, power and responsibility as well as weak communication among related government departments, the implementation power of environmental policies is affected negatively resulting weak implementation (Wu, 2010, CCICED, 2013, and Zhang, 2014). Last but not least, there exist regional disparities in environmental regulatory stringency. Because although environmental standards are set jointly by national and local regulators, the actual environmental levies are determined and collected by local regulators, some local regulators may impose less environmental levies to protect polluting enterprises for economic reason. Moreover, environmental regulatory inspections also vary across regions due to the quality of local environmental management system (Huang et al., 2006, Ma, 2007, Liu et al., 2009, and Zhang, 2014).

3.3.6 China's factor endowment at provincial level

China also has regional differences in factor endowment. As shown in figure 3.16, comparing to the world average capital to labour ratio, high income provinces in China also have relatively higher capital to labour ratios. For instance, high income provinces in China are also coastal provinces such as Beijing, Tianjin, Liaoning, Jilin, Heilongjiang, Shanghai, Jiangsu, Zhejiang, Guangdong and Hainan, have significantly higher relative capital to labour ratios than low income provinces. As discussed in the above section, high income provinces in China have better enforcement of national environmental regulations and policy initiatives on environmental issues, as well as higher capital to labour ratios than low income provinces. In other words, high income provinces in China have relatively stringent environmental regulations, and also are relatively factor abundant, whereas low income provinces have lax environmental regulations and are less factor abundant. Therefore it seems that pollution in high income and low provinces is affected by the pollution haven effect as well as factor endowment effect. This leaves us a question about the overall effect of international trade in high income and low income provinces respectively.

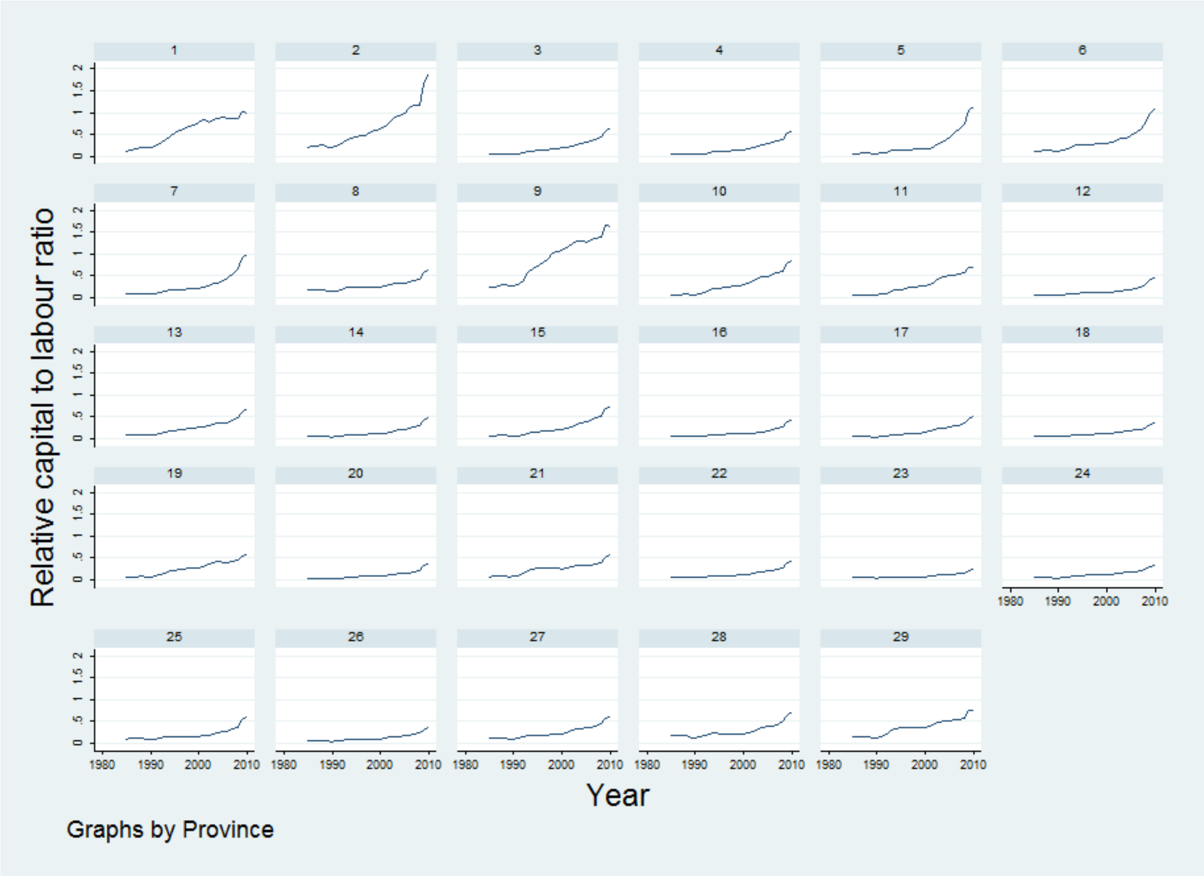

Figure 3.16: Relative capital to labour ratio
Source: National Bureau of Statistics of China.

Province code

Province/city	Code	Province/city	Code
Beijing	01	Henan	16
Tianjin	02	Hubei	17
Hebei	03	Hunan	18
Shanxi	04	Guangdong	19
Inner Mongolia	05	Guangxi	20
Liaoning	06	Hainan	21
Jilin	07	Sichuan	22
Heilongjiang	08	Guizhou	23
Shanghai	09	Yunnan	24
Jiangsu	10	Shaanxi	25
Zhejiang	11	Gansu	26
Anhui	12	Qinghai	27
Fujian	13	Ningxia	28
Jiangxi	14	Xinjiang	29
Shandong	15		

3.4 Methodology and data

This section introduces our methodology and describes the data. We follow Antweiler et al.'s (2001) theoretical model, but since our environmental indicators are pollution emissions, we apply an empirical specification proposed by Cole and Elliott (2003). In section 3.4.3, we discuss the construction of the dependent and independent variables, as well as how these variables may facilitate our study. Section 3.4.4 discusses the selection of estimator.

3.4.1 Estimation specification

Our estimation specification is derived from the theoretical model of Antweiler et al. (2001). Following the proposition by Grossman and Krueger (1991), Antweiler et al. (2001) defines total pollution (z) as the product of total output (S) multiplied by the share of dirty output in total output (φ) and pollution intensity of the dirty industry (e) as follows:

$$z = e\varphi S \qquad (3.1)$$

Antweiler et al. (2001) decomposes total pollution into the scale, composition and technique effects as follows:

$$\hat{z} = \hat{S} + \hat{\varphi} + \hat{e} \quad (3.2)$$

where hats denote a percentage change; $\hat{S}$, the scale effect, measures the changes in pollution caused by changes in size of the economy, holding other things equal; $\hat{\varphi}$ the composition effect, represents the changes in pollution due to changes in the output mix, ceteris paribus; $\hat{e}$, the technique effect, measures the effects on pollution of changes in the pollution intensity of the production process.

As discussed in section 3.2, international trade may affect pollution through direct and indirect effects, in which the indirect effect includes trade induced scale, composition and technique effects. Therefore, Cole and Elliott (2003)[45] propose an empirical specification based on the theoretical model of Antweiler et al. (2001) as follows:

$$E_{it} = a + \beta_1 KL_{it} + \beta_2 KL_{it}^2 + \beta_3 Y_{it} + \beta_4 Y_{it}^2 + \beta_5 KL_{it} Y_{it} + \beta_6 O_{it} + \beta_7 O_{it} rel.KL_{it} + \beta_8 O_{it}(rel.KL_{it})^2 + \beta_9 O_{it} rel.Y_{it} + \beta_{10} O_{it}(rel.Y_{it})^2 + \beta_{11} O_{it} rel.KL_{it} rel.Y_{it} + \mu_i + \varepsilon_{it} \qquad (3.3)$$

[45] It should be noted that both Antweiler et al. (2001) and Cole and Elliott (2003) use the lagged income in their estimation, but Antweiler et al. (2001) also include a GDP to area ratio (GDP/km^2) to capture the scale effect. However, as argued by Cole and Elliot (2003), for per capita emissions, GDP to area ratio may be no longer meaningful as a measure of scale effect. Also since we use per capita GDP as the indicator of income, keeping GDP to area ratio in the estimation equation introduces extra multicollinearity problem.

Where the dependent variable E_{it} is a pollution indicator and is proxied, in various settings, by the emissions of waste gas, waste water, solid waste, etc.; KL_{it} is the capital to labour ratio, capturing the composition effect. Using capital to labour ratio to indicate the composition effect bases on the assumption that a rise (reduce) in the capital to labour ratio reflects a rise (reduce) of dirty industry production share, since dirty industry such as manufacturing industry is assumed to have higher capital to labour ratio than clean industry such as agriculture industry. Y_{it} is GDP per capita. Since a rise in GDP may increase pollution through the scale effect, but reduce pollution through the income/technique effect, Y_{it} and Y_{it}^2 capture the scale effect as well as income/technique effect. $KL_{it}Y_{it}$ is the cross product of KL_{it} and Y_{it}, captures the interaction between capital abundant and income. If the economic growth is driven by capital intensive industries, then the coefficient of $KL_{it}Y_{it}$ should be positive. O_{it} is an international trade measure, such as trade openness ratio (exports plus imports divided by GDP) and FDI inflows ratio (FDI inflows divided by GDP); $O_{it}rel.KL_{it}$ is an interaction term of international trade and relative capital to labour ratio (defined as capital to labour ratio of each province divided by the world average capital to labour ratio); $O_{it}rel.Y_{it}$ is an interaction term of international trade and relative income (defined as income of each province divided by the world average income); $O_{it}rel.KL_{it}rel.Y_{it}$ is an interaction term of international trade, relative capital and relative income. i refers to a province; t refers to a year; α and βs are coefficients; μ_i represents provincial effect and ε_{it} is the error term.

As discussed in chapter 2 and section 3.2, there may be a nonlinear relationship between income and pollution, since a rise in income may increase pollution through the scale effect, but reduce pollution through the income/technique effect. Similarly, the relationship between capital to labour ratio and income may be nonlinear too. A rise in capital to labour ratio may increases pollution because of the composition effect as predicted by the FEH. But provinces with high capital to labour ratios also have higher income level, and in turn have better enforcement of national environmental regulations and policy initiatives on environmental issues as predicted by the PHH, so higher capital to labour ratios may lead to low pollution. Moreover, there seems to be a nonlinear relationship between pollution intensity and capital to labour ratio. For instance, it is widely believed that agricultural and service industries are cleaner than manufacturing industry, so as the economy develops from agricultural to manufacturing and then to service, pollution first goes up and then down, showing an inverted-U shape curve, the EKC curve. However, it is also revealed that capital to labour ratio rises in service industry may be higher than manufacturing industry (see data and discussion in section 3.4). Thus, it seems that as the economy develops from agricultural to manufacturing and then to service, capital to labour ratio rises. Therefore, there may be an inverted U shape relationship between capital to labour ratio and pollution, as capital to labour ratio rises, pollution first goes up and then down. Therefore, the linearity assumption about effects of Y_{it} and KL_{it} may be no longer proper, and thus square terms of both variables are included in our estimation. As proposed by Antweiler et al. (2001), square terms of capital-to-labour ratio and income per capita are introduced to the estimation to capture possible nonlinearity of the scale, technique and composition effects. The square terms of relative capital-to-labour ratio and relative income per capita are added following the same reasoning. Antweiler et al. (2001) argue that capital-intensive industries tend to be pollution-intensive. Thus provinces with a higher capital to labour ratio are expected to have proportionally more polluting industries and higher pollution emissions per capita, but the relationship between capital to labour ratio and pollution may have an inverted U shape. Therefore, β_1 is expected to have a positive sign whilst β_2 is expected to have a negative sign, and β_3 is expected to have a positive sign whilst β_4 is expected to have a negative sign. The interaction term of capital to labour ratio and income is included in the regression equation with the consideration that the impact of income gains on pollution may depend on the existing composition of output, so the sign of β_5 may be positive or negative.

Trade induced effects are captured by trade intensity and its interaction terms with relative capital to labour ratio and relative income. We assume the environmental impact of international trade depends on the comparative advantage of provinces. There are two types of comparative advantages: factor endowment and environmental regulation, respectively captured by relative capital to labour ratio and relative income. The choice of these variables is under the assumption that provinces with relatively higher capital to labour ratio have comparative advantage in dirty goods production, whereas provinces with relative higher income level have relative stricter environmental regulation thus having comparative advantage in clean goods production. Therefore, the sign of coefficient β_7 is expected to be positive and sign of coefficient β_8 is expected to be negative, implying international trade leads to relatively capital (labour) abundant provinces specialising in producing dirty (clean) goods and in turn generating more (less) pollution, but reducing pollution at higher level. Whereas, the sign of coefficient β_9 is expected to be positive and sign of coefficient β_{10} is expected to be negative, implying international trade leads to relative higher (lower) income provinces specialising in producing clean (dirty) goods and in turn improving (polluting) the environment. The three way interaction term of trade intensity, relative capital to labour ratio and relative income is different to predict, so the sign of coefficient β_{11} may be positive or negative. The trade intensity captures the rest of trade induced effects such as trade induced direct effect, trade induced scale effect and trade induced technique effect, so β_6 may be positive or negative or even equal to zero. The expected signs of coefficients are reported in table 3.6.

Table 3.6: The expected signs of coefficients

Coefficient	s	β_2	β_3	β_4	β_5	β_6	β_7	β_8	β_9	β_{10}	β_{11}
Sign	+	–	+	–	?	?	+	–	+	–	?

3.4.2 Data Description

This section describes our data set. All our data are sourced from the National Bureau of Statistics of China and China Statistical Yearbooks for various years. We collect information for 29 provinces and municipalities, excluding Taiwan, Tibet, and the two special administratives regions, Hong Kong and Macau. To avoid possible inconsistency, Chongqing data are integrated with Sichuan data under the province name Sichuan. The time span of our data covers the period 1985-2010.

Antweiler et al. (2001) argue that a good pollutant for empirical studies of their model should possess as many of the following characteristics as possible: (1) it should be a by-product from goods production; (2) it should be emitted in greater quantities per unit of output in some industries that others; (3) it should have strong local effects; (4) it should be subject to regulations because of its adverse effects on pollution; (5) it should have well-known abatement technologies; (6) it should have data available from a wide mix of countries (provinces in our study). Following this proposition, we choose our environmental indicators and other variables as follows.

Industrial waste gas

Industrial waste gas is a generic measure of the total volume of all air pollutants emitted from the production processes and fuel combustion in industrial enterprises during the reported period. It is calculated at standard status (273K, 101325Pa). Air pollutants in the industrial waste gas might include carbon dioxide (CO2), carbon disulphide (CS2), carbon monoxide (CO), hydrochloric acid, hydrogen sulphide, soot and dust. Emissions of these pollutants to the air pollute the ambient environment and jeopardize human health, for instance it may cause serious respiratory illnesses and premature deaths and incidents.

Industrial waste water

Industrial waste water measures the total quantity of industrial effluent discharged by industrial enterprises through all their outlets. It includes waste water from the production process, direct cooled water, groundwater from mining wells that do not meet discharge standards and sewage from households mixed with waste water produced by industrial activities, excluding indirect cooled water discharge (but if the discharge is not separated from waste water, then it should be included). Similar to industrial waste gas, industrial waste water is a generic measure of the total volume waste water discharged in the production process.

Industrial solid waste produced (solid waste)

Industrial solid waste produced refers to the total volume of solid waste, semi-solid waste and high concentration liquid residuals by industrial enterprises in the production process. It includes hazardous solid wastes, smelting solid waste, coal ash, slag, gangue, tailings, radioactive, residues and other wastes, but excludes stones stripped or dug out in mining (a stone is acid or alkaline according to the PH value of the water being below 4 or above 10.5 when the stone is in, or soaked by water).

In our regression, all three pollution indicators are expressed in per capita terms. Waste gas is in the unit of cubic meter, waste water and solid waste are in unit of ton. We take the natural logarithm for all variables in our estimation.

GDP

GDP is the total output of a province. Following the proposition of Cole and Elliott (2003), though in reality the scale effect is likely to be contemporaneous whilst the technique effect is likely to be associated with a lag, we use one period lag of GDP per capita for both the scale effect and technique effect. Since our GDP data are in nominal value for each province and each year, we adjust our GDP data by provincial CPIs to remove the price effect and express all GDP values in year-2000 price. Provincial CPI data are estimated utilising the provincial consumer price index from the National Bureau of Statistics of China. We set CPI in 1978 as the baseline for all provinces. This is due to two reasons. One is that before 1978, Chinese economy was central-planned economy and market economy has not been introduced, so price levels in all provinces are fixed and relatively similar. The other reason is that CPI data from the National Bureau of Statistics of China have lots of missing value for years prior to 1978. CPI values for the year 1978 are almost the same in all provinces. Therefore our estimation of Chinese provincial CPI is basing on China’s economic history as well as data limitation. Therefore, in this chapter, we use per capita GDP in the unit of year-2000 price Chinese yuan. And it is in the natural logarithm for our regressions.

Capital to labour ratio

Capital to labour ratio is defined as the capital stock divided by the total number of employed persons in one province. Our capital stock data are sourced from Zhang et al. (2007), who construct annual provincial capital stock series for the period 1952-2000 using the perpetual inventory method. It should be noted that the capital stock here only refers to physical capita, and does not include human capital accumulation. Following the methodology in Zhang et al. (2007), we estimate the capital stock data for the period 2001-2012 using updated information from the China statistical yearbook. Employment population refers to those aged 16 and over who engage in certain social labour work and receive payment. Capital to labour ratio is used to capture the composition effect.

Trade openness and FDI inflows

We use two measures for China's international trade: trade openness ratio and FDI inflows ratio. Trade openness ratio is defined as exports plus imports divided by GDP. Since it is a ratio, we calculated it by using the nominal values of exports and imports divided by the nominal value of GDP for each province and each year. FDI inflows ratio is defined as the value of FDI utilised (rather than contracted) within the year divided by GDP.

Relative capital labour ratio and relative income ratio

Previous empirical studies using cross-country panel data (e.g., Antweiler et al., 2001, and Cole and Elliott, 2003) propose to use national capital-to-labour ratios (or income) relative to the world average to estimate the trade induced composition (or technique) effect. Since our study focuses on a single country China, we calculate these two relative measures for each province against the world average. In doing so, we intend to capture the provincial differences in factor endowment effect and pollution haven effect.

3.4.3 Selection of estimator

In this section, we discuss the selection of estimator. We first run the regressions using pooled, fixed effect and random effect estimators. Secondly, we apply the Hausman test for random effect versus fixed effect models. Thirdly, we test for heteroscedasticity following the Breusch-Pagan/Cook-Weisberg test approach (Baum, 2006). Fourthly, we test for autocorrelation following the approach suggested in Drukker (2003) and Wooldridge (2010).

3.4.3.1 Fixed Effect model versus Random Effect model

Since our panel estimation includes 29 provinces, the pollution in a particular province may be affected by factors specific to this province only. Both Fixed Effect (FE) model and Random Effect (RE) model account for province-specific effects, but the RE model assumes the province-specific effects are uncorrelated with the explanatory variables. To statistically test which model is more appropriate for our study, we utilise the Hausman test (Greene, 2008, chapter 9). The null hypothesis of the Hauman test is that the preferred model is the RE model. Our Hausman test results are reported in table 3.7. Since all p-values are less than 0.05, the null hypothesis can be rejected and the Hausman test results prefer the FE model, implying the time invariant provincial fixed effects are correlated with the explanatory variables. Intuitively, we believe the FE model is more appropriate in our study. For instance, province specific factors such as geographic locations seem to be correlated with international trade since China's open-up policy, as discussed in section 3, has been biased in favour of the coastal provinces.

Table 3.7: Hausman test results

Trade openness	Waste Gas	Waste Water	Solid Waste
Chi2	23.80	61.38	41.92
P-value	0.0484	0.0000	0.0001

FDI inflows	Waste Gas	Waste Water	Solid Waste
Chi2	27.8600	31.9500	31.0700
P-value	0.0034	0.0014	0.0019

3.4.3.2 Heteroscedasticity test

One of the important assumptions in the Classical Linear Regression Model (CLRM) is that the disturbances in the regressions are homoscedastic. When the disturbances have difference variances, we have the heteroscedasticity problem. Heteroscedasticity is common in panel data analyses. In the context of this study, a number of factors may give rise to heteroscedasticity. Firstly heteroscedasticity may becaused by cross-sectional scale differences. Heteroscedasticity is generally expected if small, medium and large size of cross-sectional units are sampled together (Gujarati, 2008). In our data set of Chinese provinces, the sizes of pollution vary between provinces, so the disturbance terms of the provinces with more pollution are likely to have larger variances. Secondly, our provincial data are aggregations of micro data from cities, towns or even lower level administrative division, so there may exist cross provincial differences in collecting and calculating the data. Heteroscedasticity may arise from differences in data collecting techniques. As data collecting techniques improve over time, the variances of disturbances are likely to diminish, because data can be collected more accurately. Lastly, there are a few outliers in our data-set which can also cause heteroscedasticity problem.

We test for the presence of heteroscedasticity in our estimation using the Breusch-Pagan/Cook-Weisberg test (Baum, 2006). The null hypothesis is homoscedasticity. Our heteroscedasticity test results are reported in table 3.8. In all cases, we reject the null hypothesis of homoscedasticity, implying that our estimation is not free of the heteroscedasticity problem.

Table 3.8: Heteroskedasticity test results

Trade Openness	Waste Gas	Waste Water	Solid Waste
Chi2	12.9000	30.2900	37.7200
P-value	0.0003	0.0000	0.0000

FDI inflows	Waste Gas	Waste Water	Solid Waste
Chi2	26.0000	28.0700	34.9400
P-value	0.0000	0.0000	0.0000

3.4.3.3 Autocorrelation

Autocorrelation is also a common problem in panel data analyses. The autocorrelation problem arises when the disturbances between adjacent periods are highly correlated. In our data-set, since pollution is mainly generated from dirty production processes and pollution normally cannot be reduced suddenly, autocorrelation may be a problem.

We test for the presence of first-order autocorrelation following the Wooldridge (2010) approach. The null hypothesis is there is no first order autocorrelation. Our test results are reported in table 3.9. At the 95% confidence level, our autocorrelation test results suggest we can reject the null, implying we have the autocorrelation problem.

Table 3.9: Autocorrelation test results

Trade Openness	Waste Gas	Waste Water	Solid Waste
F	46.5340	62.9860	60.0830
P-value	0.0000	0.0000	0.0000

FDI inflows	Waste Gas	Waste Water	Solid Waste
F	29.5220	61.5420	58.2170
P-value	0.0000	0.0000	0.0000

3.4.3.4 Heteroscedasticity and autocorrelation robust estimator

The results from the tests for heteroscedasticity and autocorrelation in sections 3.4.4.2 and 3.4.4.3 suggest that our regression model may suffer from heterscedasticity and autocorrelation problems. With heterscedasticity and autocorrelation, the usual OLS estimator, though linear, unbiased and asymptotically (i.e., in large samples) normally distributed, no longer has the minimum variance among all linear unbiased estimators. In short, they are not efficient relative to other linear and unbiased estimators. Furthermore, the usual t, F and χ^2 tests may not be valid.

To obtain heterscedasticity and autocorrelation robust standard errors for our estimation, we utilise the Newey-West estimator (Newey and West, 1987). In the Newey-West estimator, an integer (g) representing the order of autocorrelation needs to be selected. It is suggested that for annual data, this integer should be small, such as 1 or 2; alternatively others suggest that an optimal integer equals to $n^{1/4}$ should be used, since the optimal integer should grow with the sample size n (Wooldridge, 2009). However, in our case, the estimation results with integers of 2 and 5 ($g = n^{1/4} = 751 \approx 5$) are qualitatively similar, so we choose to present the estimation results obtained by $g = 2$.

3.5 Results

In this section we present and discuss the results from fixed-effect estimation with the variance-covariance matrix estimated by the Newey-West estimator. The results are reported in table 3.10 and 3.12.

Table 3.10: Estimation results with trade openness as the measure of trade

	Waste Gas	Waste water	Solid waste
KL	-0.8515*	-0.9294*	-0.6067*
KL square	-0.0083	0.0309	-0.0228
Y	3.8282***	4.3926***	2.7333***
Y square	-0.1830***	-0.2024***	-0.1381***
KL*Y	0.0927	0.0302	0.1103
O*rel.KL*rel.Y	0.1822	0.3908	0.1209
O	-0.0954*	0.0405	-0.0513
O*rel.KL	0.1943*	0.0775	0.1178
O*(rel.KL)^2	-0.1285**	-0.2296**	-0.0349*
O*rel.Y	0.0312	-0.1393	0.0429
O*(rel.Y)^2	-0.3102**	-0.0351	-0.3160**
Time trend	-0.0348	-0.1115	-0.0608
Constant	58.0083**	204.8378**	105.5231**
Turning point	34,876.3016	51,600.3939	19,852.5907

Emissions of waste gas, waste water and solid waste are expressed in per capita terms. KL: capital labour ratio. Y: GDP per capita. O: trade openness. rel.KL: relative capital labour ratio. rel.Y: relative income ratio.
,,*** represents 10%, 5% and 1% significance level respectively.*

Table 3.11: Estimation results with FDI inflow ratio as the measure of trade

	Waste Gas	Waste water	Solid waste
KL	-0.9951**	-0.5225*	-0.6674**
KL square	0.0218	0.0133	0.0291
Y	4.6789**	4.0422**	4.1559**
Y square	-0.2219**	-0.1817*	-0.2046**
KL*Y	0.0687	0.0285	0.0939
FDI*rel.KL*rel.Y	-0.1759	-0.3235*	-0.1257
FDI	0.0406*	-0.0301	0.1027**
FDI*rel.KL	-0.0665*	-0.0563*	-0.1341**
FDI*(rel.KL)^2	0.0603	0.1381	-0.0068
FDI*rel.Y	0.1902	0.0361	0.2471
FDI*(rel.Y)^2	0.0957	0.1984	-0.0082
Time trend	-0.0579	-0.1142	-0.0541
Constant	100.1422**	209.8501**	91.4390**
Turning point	37,904.0057	67,729.7047	25,749.1876

Emissions of waste gas, waste water and solid waste are expressed in per capita terms. KL: capital labour ratio. Y: GDP per capita. FDI: FDI inflows. rel.KL: relative capital labour ratio. rel.Y: relative income ratio.
,,*** represents 10%, 5% and 1% significance level respectively.*

3.5.1 Non-trade variables

We first discuss the non-trade variables. The signs of the coefficients on the capital to labour ratio and capital to labour ratio squared are not as expected. The capital to labour ratio (K/L) is expected to have a positive sign and capital to labour ratio square $(K/L)^2$ is expected to have a negative sign. In empirical studies using cross country data, both Antwerlier et al. (2001) and Cole and Elliott (2003) find that (K/L) has a positive sign representing increases in capital to labour ratio raises pollution, and $(K/L)^2$ has a negative sign implying additional increase in capital to labour ratio has a diminishing impact. Their results support the argument that changes in production composition towards to capital intensive activities cause more pollution. However, we cannot find any evidence supporting this argument. Instead we find that the capital to labour ratio is inversely related to all three pollutants. Thus our results suggest a rise in capital to labour ratio reduces pollution.

As assumed in many theoretical studies, Antwerlier et al. (2001), Copeland and Taylor (1997 and 2004) to name a few, capital intensive industries are often treated as more pollution-intensive than the rest. This assumption is based on the conventional wisdom that labour intensive industries such as agriculture and services typically require relatively less physical capital input and generate less pollution, whereas manufacturing industries are widely believed to be more capital intensive and cause more pollution. This assumption has received support in a number of empirical studies. For instance, Antwerlier et al. (2001) finds capital abundance (capital to labour ratio) is positively related to SO_2 concentration. In an empirical study of four air and water pollutants, Cole and Elliott (2003) show a rise in the capital to labour ratio increases local pollutant SO_2 as well as global pollutant CO_2 both in terms of emissions and concentration. Utilising a world panel of 128 countries, Kellenberg (2008) provides strong evidence of a positive relationship between capital intensity and the emissions of four local pollutants: SO_2, NO_x, CO and VOC. Empirical evidence of capital abundance increasing pollution is also found in studies of pollution in China. Shen (2008) finds a rise in capital to labour ratio increases the volumes of SO_2, dust, COD, Arsenic and Cadmium discharge at the provincial level. Empirical evidence of a positive relationship between the emissions of various pollutants and the capital to labour ratio is also been found in Copeland and Taylor (1994 and 1997), Cole et al., (1997), He (2009), He and Wang (2012) among others.

However, our results cast doubt on whether higher capital to labour ratios necessarily mean higher pollution intensity. For instance, the agricultural sector is long believed to have low capital intensity, but it is an important contributor to water pollution, soil erosion, and global warming. As reported by the United Nations Food and Agricultural Organisation (FAO), about 18% of anthropogenic greenhouse gases (GHG) emissions come from the world's livestock. It is also well known that agriculture is the single largest user of freshwater resources, consuming a global average of 70% of all surface water supplies (FAO, 2006). Meanwhile, agriculture activities discharge pesticides and fertilizers into surface and/or ground water causing water pollution. In contrast, the real estate sector is a clearly highly capital intensive sector as it requires massive investment in property, but buying, selling, and renting real property generally causes little pollution.

In the case of China, on the one hand, some sectors that are conventionally believed to be pollution intensive may not be capital intensive. As shown in table 3.12[46], the mining sector is often held as one of the most environmentally unfriendly sector, since it damages the environment by causing erosion, loss of biodiversity deforestation, and contamination of water resources (Down and Stocks, 1977, and Hilson and Murck, 2000 among others). However the fixed assets investment to employed person ratio is actually very low in mining sector. For instance, the fixed assets investment to

[46] We are not able to find capital stock data for disaggregated sectors to calculate sectorial capital to labour ratios in the conventional way. Table 3.12 reports the annual fixed assets investment to employed person ratio. This calculation has obvious drawbacks, due to its arbitrary treatment of initial investment before the sample period. But it nevertheless tells some information about which sector is actually contributing to China's capital stock growth.

employed person ratio is only 21.08, less than the average of 24.59 in China. Similarly, manufacturing sector is also believed to be heavy polluting, but it only has a relatively low fixed assets investment to employed person ratio (29.22), just slightly more than the average level (24.59), and even lower than the agriculture sector (32.45). On the other hand, some sectors with high fixed assets investment to employed person ratio may be relatively clean in conventional wisdom. In table 3.12, the highest fixed assets investment to employed person ratio is form the real estate sector, it is not difficult to understand due to the large investment. Especially China's red-hot property market attracts lion amount of capital inflows every year and the house prices in China keep hitting the record high. However, conventionally, real estate sector is not considered as polluting sector, at least not as polluting as manufacturing and mining industries. Table 3.12 tells that industries with high fixed assets investment to employed person ratio may not necessarily generate more pollution, implying that high capital intensive industries may not necessarily mean high pollution intensive, at least in China. Our estimation results seem to support this argument.

The coefficients of income and income squared have the expected signs and are both statistically significant. As predicted by the EKC, the relationship between income and pollution has an inverted U shape, which implies as income rises pollution first goes up and then goes down after a threshold level of income. This threshold level of income is called the EKC turning point. Table 3.10 shows β_3 is positive and β_4 is negative, our estimation results support the EKC hypothesis and suggest the relationship between income and three local pollutants in Chinese provinces has an inverted U shape. Our estimated turning points of waste gas, waste water and solid waste are respectively, 34,876, 51,600, and 19,852 with trade openness as the measure of trade, and 37,904, 67,729 and 25,749 with FDI inflow ratio as the measure of trade (table 3.11). As shown in table 3.2, all provinces have a lower income than all turning points in the year 1985, but in the year 2010, some rich provinces have income levels higher than the turning points. This indicates that rich provinces have moved from the left to right of the EKC in Chinese provinces over the period 1985-2010. For instance, eastern (rich) provinces such as, Beijing, Guangdong, Jiangsu, Shanghai, Tianjin and Zhejiang, have passed the turning points of waste gas; Beijing, Shanghai, and Tianjin have passed the turning points of waste water and solid waste (in trade openness equations). Our results suggest that except few rich provinces, most Chinese provinces are still lying on the left of the EKC curve, implying further economic growth only causes few rich provinces becoming cleaner, but leads to most poor provinces becoming dirtier. This finding also implies that the relative strength of scale effect and technique effect are different in rich and poor provinces. In rich provinces, technique effect dominates scale effect, whereas in poor provinces scale effect dominates technique effect. It should not be difficult to understand that in rich provinces such as Beijing, Guangdong, Jiangsu, Shanghai, Tianjin and Zhejiang, because the income levels are high enough, people living in these rich provinces would like scarifying some of their income for better environment, and in turn they put more pressure on polluting activities forcing the technique improvement and resulting pollution reduction. However, in the poor provinces, the income levels are not high enough, people still prefer income rather than environment, and therefore economic growth in poor provinces is still at the cost of environment. Comparing to the existing literature, our estimation results show higher turning points than previous empirical studies. For example, Jiang et al. (2008) find that turning points of waste water in Chinese provinces are 43,980, 13,307 and 21,290 (2000 price Chinese yuan) for costal, central and western provinces respectively; Song et al. (2008) find turning points of waster gas, waste water and solid waste are respectively, 29,017, 9,705 and 28,296 (2000 price Chinese yuan). However, these results are from the estimation basing a fraction of our dataset prior to the year 2005. We think our estimation results are more accurate not only because we use a larger and more updated dataset, but also because it is evident by mass media that pollution is not significant reducing in most Chinese provinces.

Table 3.12: Annual fixed assets investment divided by number of employed persons

Year	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Total average	**5.0655**	**6.3499**	**7.7844**	**9.3910**	**11.4204**	**14.1750**	**17.8636**	**19.2839**	**21.6110**	**24.5921**
Agriculture	3.4103	4.0564	5.2065	6.3188	7.9838	12.3493	18.4503	21.0889	24.3611	32.4474
Mining	3.6354	4.7850	7.0451	8.8322	10.9884	14.2594	16.6351	19.5746	19.2070	21.0790
Manufacturing	4.9285	6.4198	8.2768	10.1711	12.8427	16.5106	20.2219	24.3647	25.1236	29.2220
Electricity, Gas & Water	13.3145	19.2785	25.1898	28.3824	31.2049	35.8799	46.9111	50.4983	43.7997	48.3827
Construction	1.1088	1.1462	1.2076	1.1384	1.2393	1.4506	1.6921	2.2108	1.9464	1.8599
Transport, Storage & Post	9.8812	12.1023	15.6606	19.8109	22.7155	27.1391	39.3674	47.6541	42.6851	47.1085
Information	14.2182	13.4007	12.1580	13.5739	12.3042	13.5589	14.8961	13.2104	10.2183	12.0824
Wholesale & Retail Trades	1.4691	2.1697	3.1551	4.3927	5.6822	7.2742	9.8556	11.2730	11.4895	13.7829
Hotel, Catering Service	2.4578	3.1665	4.4634	5.9581	8.1778	10.1409	12.9905	16.0935	16.3026	19.4397
Financial Intermediation	0.2552	0.3821	0.3046	0.3305	0.4043	0.6239	0.8021	1.0410	1.2641	1.7505
Real Estate	109.3463	125.0290	133.1421	159.3527	194.8282	234.1738	258.5569	306.6034	328.5843	362.2920
Leasing & business service	2.0465	2.1647	2.5151	3.0653	3.8404	4.9358	7.0092	8.6829	11.8033	16.0807
Research	1.2880	1.5000	1.9109	2.1034	2.3009	3.0428	4.4051	4.7187	5.6274	7.4864
Management	25.3091	28.8003	34.7799	43.5972	52.4771	68.5977	96.6182	113.4198	106.4835	121.4994
Household Service	4.5759	5.7880	6.7432	6.8809	7.5728	9.2389	13.6383	18.5060	24.0947	30.6768
Education	1.1583	1.3804	1.4895	1.5091	1.5619	1.6452	2.2711	2.5500	2.4073	2.7900
Social Welfare	0.8353	1.0445	1.3005	1.4636	1.6305	2.0504	3.1196	3.3502	3.4314	3.6385
Culture	4.1589	6.2672	6.9962	7.8057	9.9469	12.6185	18.4046	22.5221	23.4220	31.0186
Public	1.8392	2.0329	2.3588	2.3629	2.4520	2.8079	3.3966	3.9738	3.8483	3.9231

Investment is expressed in units of 100,000,000 RMB, and labour is in units of 10,000 people, so the unit for the figures reported in this table is RMB 10,000 per worker. Source: National Bureau of Statistics of China.

3.5.2 Trade variables

The Factor Endowment Hypothesis (FEH) posits that the environmental impact of trade depends on a country's underlying production capabilities: if a country is relatively abundant in factors used intensively in polluting (clean) industries, then international trade will aggravate (improve) its environment. By contrast, the Pollution Haven Hypothesis (PHH) emphasises the effect of environmental regulation: a country with relatively weak (strict) environmental regulation has a comparative advantage in dirty (clean) goods production, ceteris paribus. The equation (3) of the empirical model presented in section 3.4.1, attempts to capture both the factor endowment effect (FEE) and pollution haven effect (PHE). Because relative capital to labour ratio reflects a province's relative capital endowment, the interaction of trade/FDI with the relative capital to labour ratio captures the trade/FDI induced composition effect. The interaction of trade/FDI with relative income captures the trade/FDI induced PHE, since the stringency of environmental regulation is believed to be positively related to the income level (Dasgupta et al., 2002).

In the existing empirical studies, Antweiler et al. (2001) and Cole and Elliott (2003) provide evidence for both FEH and PHH, since they find the interaction term of trade and relative capital to labour ratio has a negative coefficient and its square has a positive coefficient, whereas the interaction term of trade and relative income has a positive coefficient and its square has a negative coefficient. Their results suggest that trade induced composition effect reduces pollution in relatively less capital abundant countries but raise pollution in relatively capital abundant countries, whereas trade induced technique effect raises pollution in relatively low income countries but reduces pollution in relatively high income countries.

However, in our estimation for Chinese provinces, we find that β_7 is positive but statistically insignificant (or only significant at 10% level), and β_8 is negative in the trade openness equations, whereas β_7 is negative and β_8 is statistically insignificant in the FDI equations (table 3.11). Our results suggest that international trade reduces pollution as capital to labour ratios in Chinese provinces. This finding seems to coincide with previous empirical studies, since it implies that the FDI inflows in provinces with low capital to labour ratios reduce pollution as suggested by β_7 in the FDI equations. However, since in the trade openness equations, β_8 reveals that trade openness reduces pollution in provinces with high capital to labour ratios. Our results in fact consistently reveal a negative trade induced composition effect in Chinese provinces. This finding should not be too surprising since we find that higher capital intensity (measured by capital to labour ratio) may not necessarily mean pollution intensity in China as discussed in section 3.5.1.

With regards to trade induced income/technique effect, our results show that only β_{10} in the trade openness equations is negative and statistically significant. This result suggests the trade induced income/technique effect is positive to the environment, implying that trade openness reduces pollution in high income provinces. This finding reveals that strict environmental regulations affect the trade openness in rich Chinese provinces towards to more environmentally friendly, supporting the PHE. Since, both β_9 and β_{10} are statistically insignificant in the FDI equations, these results tell us that the FDI inflows to China is not a significant factor to China's industrial pollution. Our results are not difficult to understand since as reviewed in section 3.3.3, Chinese government introduced series of FDI policies to guide the FDI inflows in the early 1990s, encouraging more environmentally friendly FDI inflows and restricting FDI inflows that cause serious environmental costs.

Lastly, β_6 is statistically insignificant (or only significant at 10% level) in all trade openness equations and FDI equations, implying there is no significant direct effect of trade openness and the FDI inflows on China's pollution. This finding supports Antweiler et al.'s (2001) prediction that international trade per se should not affect pollution.

In sum, our empirical study of Chinese provinces shows interesting results as follows. Firstly, we find that higher capital intensity (capital to labour ratio) may not necessarily mean high pollution intensity, at least for China. Secondly, there is an inverted U shape EKC curve between income and pollution in Chinese provinces. Although most Chinese provinces are still on the upward sloping side of the EKC curve, some rich provinces such as Beijing, Tianjin and Shanghai, may have already passed the turning points. Last but not least, we do not find statistically significant evidence that trade openness or FDI inflows cause pollution in Chinese provinces. Instead, our results reveal a negative trade induced composition effect, suggesting trade openness and FDI inflows affect the composition of Chinese economy towards to more environmentally friendly. We also see a negative trade induced technique effect in rich provinces, suggesting income rises and technology upgrades induced by trade reduce pollution in rich Chinese provinces.

Our results provide some policy implication. Firstly, since economic growth is likely to increase pollution in low income provinces, to achieve more environmentally sustainable development, the Chinese government should pay more attention to low income provinces, because low income provinces are less willing to pay for the environment and therefore are more likely to have lax enforcement environmental regulations and become pollution havens. Secondly, the environment impact of economic growth differs across provinces. Since there exist significant regional disparities in economic development, international trade and pollution, the government should design differentiated policies for different provinces. Thirdly, because international trade may have positive as well as negative environmental impact in Chinese provinces, the government should promote the positive impact through encouraging advanced technology embedded trade flows/FDI inflows, at the same time limit the negative effect through controlling trade flows/FDI inflows to dirty industries. Last, since international trade has no significant negative environmental impact in Chinese provinces, promoting international trade will not cause environmental degradation in Chinese provinces, instead it should reduce pollution through the negative trade induced composition effect and technology effect.

3.6 Conclusion

The existing literature disentangles the income growth-environment relationship into three effects: scale effect, composition effect and technique effect. Analogously, international trade affects the environment also through these three effects. Following Antweiler et al. (2001) and Cole and Elliott (2003), we carry out an empirical study of the environmental impact of trade in China at the provincial level. Firstly, our results suggest that capital intensity (as measured by the capital to labour ratio) may not necessarily mean pollution intensity. Secondly, our results provide evidence that both scale and technique effects have shaped an inverted U shape EKC curve between economics growth and pollution in China. Income rises may have different environmental impact in different provinces: income rises are likely to increase pollution in poor provinces but reduce pollution in rich provinces. Thirdly, our results show that international trade seems to positively affect the environment in Chinese provinces, indicating international trade should be further promoted. Lastly, we only see a negative trade induced technology effect on pollution in rich Chinese provinces. This finding suggests that the Chinese government should introduce differentiated international trade policies for poor and rich provinces. Particularly, policy should try to promote the technique effect in low income provinces.

Methodologically, our study is subject to a number of limitations. Firstly, as proposed by Dean (2002), He (2006 and 2007) and Bao et al. (2010), the simultaneous equation model (SEM) approach may be better for describing trade induced scale, composition and technique effects. To implement the SEM approach in our case would require various data such as pollution from foreign capital sector, environmental regulations and environmental investment etc. Therefore, data constraints dictate that the SEM analysis be left for future research. Secondly, related to the first limitation, it may be questioned that some of the explanatory variables in our model are not strictly exogenous. For example, trade openness and FDI inflows, as reviewed in section 3.2, government trade policy may be influenced by environmental regulations determined by domestic environmental issues. Hence, the results reported in table 3.10 and 3.12 are liable to the simultaneity bias. However, as demonstrated by Antwerlier et al. (2001) and Cole and Elliott (2003), the independent variables in our empirical model are not simultaneously determined, but our empirical model are derived recursively. The recursive nature of our reduced form empirical specification ensures the OLS estimates are unbiased and consistent. Thirdly, as reviewed in section 2, our estimation may also suffer from the unit root problem. Several unit root tests designed for panel data, including the Pesaran (2007) test, were conducted and the results indicate that our variables are stationary. These unit root test results are available from the author upon request. Lastly, we allowed for potential cross section dependence following the approach proposed in Driscoll and Kraay (1998). However, these re-estimated results are not qualitatively different from those obtained using the fixed effect estimator with heteroskedasticity and autocorrelation robust errors. These results are also available from the author upon request.

Moreover due to lack of data, we have not taken into account the inter-provincial trade among Chinese provinces. Some concern that missing inter-provincial trade may lead our estimation to bias results, because our data do not account for any possible indirect linkages thru international trade, which may cause our trade openness variable estimating the openness level for Chinese provinces with bias. Since we cannot find any inter-provincial trade data, we are not even sure which direction this bias may go, but our provincial trade data are the closest proxy for openness level for Chinese provinces to our knowledge.

Chapter 4: Sustainable Development and Trade Openness: Evidence from Chinese Provincial Green GDP

4.1 Introduction

"Trade is one of the best means to achieve and promote sustainable development" (Commission on Sustainable Development, OECD, 2000).

The popularity of the idea of sustainable development (SD hereafter) has made the relationship between international trade and SD a new focus in many international trade conferences as well as a growing body of academic research. Opponents of trade assert that international trade is clearly bad for SD, because trade stimulates economic growth, which leads to natural resource depletion and pollution, deteriorating the environment. However, proponents of trade disagree and argue that international trade can increase productivity and improve resource efficiency, so it is good for SD. These debates reveal the complexity in the relationship between international trade and SD.

Broadly speaking, the impact of international trade on SD may be decomposed into two effects: direct effect and indirect effect. International trade increases trade activities, which leads to rises in transportation and energy consumption generating pollution (Cristea et al., 2013). This effect is known as the direct effect. The indirect effect works mainly through economic growth. It is widely discussed that economic growth has three effects on the environment: scale effect, technique effect and composition effect. The scale effect refers to the environmental impact of a simple scale-up in the economy, which monotonically increases environmental degradation ceteris paribus. The technique effect refers to the environmental impact of environmentally efficient technology upgrade, which reduces the pollution intensity of production processes, and reduces environmental degradation ceteris paribus. The composition effect refers to changes in the share of polluting production in total domestic production. Holding the technology of production and scale of economy constant, greater damage will be done to the natural environment if more resources of the economy are devoted to polluting production processes (main publications are Grossman and Krueger, 1995, de Bruyn, 1997, Antweiler et al., 2001, Stern, 2002, and Copeland and Taylor, 2004). It is through these effects that international trade affects the natural environment and therefore SD. Thus the overall impact of international trade on SD is the result of interactions between these direct and indirect effects.

Therefore, whether international trade is good or bad for SD is ultimately an empirical issue. In the existing literature, Talberth and Bohara (2006) find that trade openness has a negative nonlinear effect on Green GDP growth, implying that growth in international trade is bad for SD but good for SD after a certain threshold. However, Talberth and Bohara's (2006) empirical study is based on the experience in developed countries,[47] but SD is widely believed to be a bigger challenge for developing countries than for developed countries because developing countries account for a larger share of the world's population and have more serious environmental issues (see chapters 1 and 2). This chapter is directly motivated by Talberth and Bohara (2006) and offers a complementary empirical study focusing on one developing country: China. In the past 50 years, one of the prominent economic phenomena is the rise of the Chinese economy. After performing double-digit growth for more than three decades and lifting hundreds of millions of Chinese out of abject poverty, China is now the world's largest economy by Purchasing Power Parity, the largest exporter and second largest importer (IMF, 2014). While China's economy grows rapidly, its environment is deteriorating fast. China faces severe environmental issues such as air pollution, water pollution, solid pollution, natural resource depletion, deforestation and desertification etc. (see chapter 2 for detail). Increasing environmental pressure makes it imperative that China shifts from resource-intensive and pollution-intensive growth to more sustainable and cleaner growth. By calculating Green GDP for Chinese provinces, and utilising these data to investigate the GDP-Green GDP relationship and trade-Green GDP relationship, this chapter attempts to shed some light on the relationship between economic growth, international trade and SD in China.

Our contribution to the existing literature is threefold. First, scant effort has been made to estimate China's provincial Green GDP. Liu and Guo (2005) provide estimates for a short time span of six years (1998-2003). This chapter applies their methodology to produce estimates for 26 years covering the period of 1985-2010. Second, the results obtained in this chapter offer new evidence on the Threshold Hypothesis (TH hereafter). Previous studies about the TH are conducted exclusively at the national level (Max-Neef, 1995, Jackson and Stymne, 1996, Neumayer, 2000, Lawn, 2005 and 2006a, and Lawn and Clarke, 2010 among others). To our knowledge, this chapter is the first study that investigates the TH at a sub-national level (China's provincial level). Third, there are very few studies on the impact of international trade on Green GDP. To our knowledge, there is only one paper - Talberth and Bohara (2006). Utilising developed countries' Green GDP data, Talberth and Bohara (2006) find that trade openness has a negative nonlinear effect on Green GDP growth, implying that growth in international

[47] In Talberth and Bohara's (2006) work, they utilise a data set of eight countries, in which seven of them are developed countries, except only one developing country: Brazil.

trade is bad for SD but good for SD after a certain threshold. Our study focuses on China, and finds trade openness growth has a positive nonlinear effect on Green GDP. From these findings, we propose the following hypothesis:

The relationship between trade openness and sustainable development are nonlinear and has different shapes in developed and developing countries. In developed countries, the relationship between trade openness and sustainable development has a U shape; whereas in the developing countries, the relationship between trade openness and sustainable development has an inverted U shape.

The aim of this chapter is to examine empirically the relationship between international trade and SD. Chapter 3 studies empirically the impact of international trade on pollution, focusing exclusively on the relationship between international trade and environmental degradation, but it does not account for the impact of international trade on economic development. However, SD demands a development that protects the natural environment, and at the same time brings economic prosperity (see section 4.2). As proposed by the Pollution Haven Hypothesis and Trade-led Growth Hypothesis (see chapter 2), international trade may affect the natural environment as well as economic growth. Therefore, in order to examine the overall effect of international trade on SD, this chapter first calculates an indicator of SD, the Green GDP, and then carries out an empirical study by utilising a conventional growth model, the Solow growth model.

The remainder of this chapter is organised as follows. Section 4.2 introduces the concept of SD, followed by a discussion of various SD indicators in section 4.3. Section 4.4 outlines empirical methodology and describes our data. Section 4.5 presents the results, and section 4.6 concludes.

4.2 Sustainable Development

The idea of SD is raised due to the concern about the resource-intensive growth after World War II. According to the United Nations' (UN hereafter) Brundtland Report (1987), SD consists of two main themes: meeting the present needs and protecting the ability to meet future needs. The UN's definition of SD reveals two main threats faced by humanity: poverty and environmental degradation. This section introduces the basic concept of SD and sets up the conceptual background for SD indicators such as Green GDP.

Nowadays, SD becomes one of the most popular catchphrases in environmental economics. But what exactly does it mean? This question is still difficult to answer. The difficulty is largely due to the lack of consistency in the interpretation, since SD means different things to different people (Lele, 1991, and Hanley et al., 2001). The most well-known definition of SD is presented by the Brundtland Report, which describes SD as: "*Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" (World Commissions on Environment and Development, the Bruntland Commissions report, the United Nations, 1987). According to this definition, SD consists of two key concepts: "needs" and "limitations". On the one hand, "needs" refer to the essential needs of the world's poor, to which overriding priority should be given. That is to say, the top priority of SD is to reduce poverty for the current generation. On the other hand, "limitations" refer to the limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs. In other word, SD proposes a development path that increases economic prosperity and improves the quality of life for human at the minimum cost of the natural environment without doing damage to the prospects of future generations.

4.3 SD Indicator: Green GDP

Since the UN's release of the definition of SD, there has been a long standing debate on how to measure SD. Especially, the popularity of SD indicators was catalysed by the Rio de Janeiro Earth Summit held in 1992, in which the world's nations agreed to produce annual statistics on the sustainability of their economies (Bell and Morse, 2008 and Hanley et al., 2013). Since then, hundreds of different SD indicators have been put forward; detailed discussion and review of various SD indicators are provided in Hamilton (1994), Hanley (2000), Lawn (2006a), Bell and Morse (2008), and Fleurbaey (2009). In this chapter, we exclusively focus on one group of SD indicator: Green GDP, due to reasons as follows. Firstly, our study on the Threshold Hypothesis (TH) and Contracting Threshold Hypothesis (CTH) requires calculation of Green GDP. Secondly, Green GDP is also needed for carrying out the investigation on the effect of international trade on China's Green GDP. Lastly, it is a long pursuit of Chinese government to develop a Green GDP index as a new measure of national well-being for replacing the conventional GDP (Rauch and Chi, 2010). Thus, this section first discusses GDP and shortcomings of GDP as an indicator of SD, and then introduces Green GDP, especially China's attempt to develop a Green GDP index.

4.3.1 GDP

Gross Domestic Product (GDP) has conventionally been used as an indicator for standard of living, but it may not be an appropriate indicator for SD. GDP is defined as the market value of all final goods and services produced within a country in a given period of time. The most common approach to measuring and understanding the GDP is the expenditure approach calculated by the formula as follows:

$$GDP = C + I + G + X - M \qquad (4.1)$$

where, C is consumption consisting of private (household) final consumption expenditure, including expenditures on services, durable and nondurable goods; I is investment, such as business investment in equipment; G is government expenditure, which is the sum of government expenditures on final goods and services; X is exports including goods and services exported (domestic production for other nations' consumption); and M is imports including goods and services imported (foreign supply for domestic consumption).

What this calculation measures is the total value of goods and services that are circulated within the country. While GDP is commonly taken as a measure of a country's economic performance, it is also well known to suffer from some deficiencies. England (1998), Lawn (2003 and 2006a), and Costanza et al. (2009) provide detailed reviews of the shortcomings, which in summary, may be described as follows. Firstly, GDP does not account for the distribution of income among individuals, which is often believed to have a considerable effect on individual and social well-being (Wilkinson and Pickett, 2009). Secondly, it also improperly interprets welfare-reducing activities as positive economic growth. For instance, flooding, earthquake and poor public health are treated as increases to GDP since they trigger growth in wage and economic output from construction and medical care. Moreover, GDP does not take into account non-market social activities either, such as housework, parenting, volunteer work, crime, and unemployment etc. Last but not least, GDP also ignores one important factor contributing to the human welfare: the environment, including environmental degradation, natural resource depletion, lost value in material discards, and related social and economic costs such as poorer health due to heavy pollution.

Since GDP is not a good indicator of SD, then which indicator is the one and what should this indicator include? Insomuch as SD is defined as development that meets the needs of the present without compromising the ability of future generations to meet their own needs, economists find inspiration from two definitions of income: Hicksian income and Fisherian income, and put forward Green GDP indices such as Sustainable Net Domestic Product (SNDP), Index of Sustainable Economic Welfare (ISEW) and Genuine Progress Indicator (GPI) (Hamilton, 1994, Lawn, 2003, Lawn, 2006a, Talberth and Bohara, 2006).

4.3.2 Sustainable Net Domestic Product (SNDP)

Hicks (1946) points out that the practical purpose of calculating income is to indicate the maximum amount people can produce and consume without undermining their capacity to produce and consume the same amount in the future. Adhering to Hicks' definition of income, Daly (1996) develops a Green GDP index for measuring a nation's income: the Sustainable Net Domestic Product (SNDP), which has a formula as follows:

$$SNDP = GDP - DHK - DRE - DNK \qquad (4.2)$$

where:

GDP: Gross Domestic Product

DHK: depreciation of human-made capital

DRE: defensive and rehabilitative expenditures

DNK: depletion of natural capital

Human-made capital and natural capital are as defined in section 4.2.2, and defensive and rehabilitative expenditures refer to the output of economic activities that is not directly consumed but specifically set aside to defend a nation's citizens from the side-effects of past and present economic activities. Examples of defensive and rehabilitative expenditures include pollution abatement costs.

As shown in the formula, the SNDP adjusts the conventional GDP by deducting the value that is not for consumption but used for keeping the total capital stock intact to avoid long-term impoverishment. The SNDP provides a measure of maximum amount a nation can produce and consume without undermining its capacity to do so in the future. It may be worth noting that the SNDP can be a measure of weak sustainability as well as strong sustainability depending on the replacement cost of natural resource depletion. If the replacement cost of natural resource depletion is not included, the SNDP keeps the combined stock of human-made capital and natural capital intact, implying human-made capital and natural capital are substitutable. In this case, the SNDP measures the weak sustainability. Whereas if the replacement cost of natural resource depletion is accounted for as proposed by El Serafy (1989), then the SNDP becomes a strong sustainability measure of national income. The replacement cost of natural resource depletion is the value used for keeping the natural capital intact, such as expenditure on cultivating additional renewable resources stocks and renewable resources substitutes for non-renewable resources, subtracting the replacement cost of natural resource depletion form GDP ensures the SNDP measuring the strong sustainability.

While the SNDP is a better measure of SD than GDP, it has deficiencies too. One obvious shortcoming of SNDP is that it does not take into account any social cost or benefit, such as cost of leisure time reduction, cost of crime, cost of unemployment, value of volunteer work, value of parenting and non-paid housework etc. (Lawn, 2003 and 2013).

4.3.3 Index of Sustainable Economic Welfare (ISEW) and Genuine Progress Indicator (GPI)

Compared with SNDP, Index of Sustainable Economic Welfare (ISEW) and Genuine Progress Indicator (GPI) measure SD based on Fisher's definition of income (Lawn, 2003). Fisher (1906) argues that the national dividend consists not of the goods produced in a particular year, but of the services enjoyed by the ultimate consumers of all human-made goods. It is in this principle that ISEW and GPI adjust consumption of an ultimate consumer with unaccounted for benefits and costs by conventional GDP. Thus, ISEW and GPI include elements that provide comparatively more complete measurement than the conventional GDP does.

Table 4.1 shows that unlike SNDP which starts with GDP, ISEW and GPI begin from the personal consumption expenditure. In the common calculating process, ISEW and GPI make adjustment on personal consumption expenditure by first accounting for income inequality, then adding net change of fixed capital, and services from durables and non-market labour or socio-environmental activities, and then deducting costs of durables and disservices generated from irksome activities, and at the last subtracting depreciation and ecological capital (the environment including both resource depletion and environmental degradation).

It should be noted that ISEW and GPI may vary greatly in the items included and differ in the valuation methods. The reasons for these variations in items and valuation methods are usually related to the availability of data and the preference of researchers (see, for instance Jackson and Marks, 1994, Jackson and Stymne, 1996, Stockhammer et al., 1997, Hamilton and Denniss, 2000, Bleys, 2006 and 2007, and Talberth, et al., 2006). Table 4.2 summarises ISEW and GPI items in case studies of the US, the UK, Australia and Austria, providing evidence that though with the same index names, ISEW and GPI in these four countries consist of significantly different elements. For example, the value of volunteer work is only accounted for in the US GPI, and costs of unemployment and overwork are only considered in the Australian GPI; whereas expenditure on consumer durables is included in the UK and Austrian ISEW.

Moreover, as pointed out by England (1998), Neumayer (1999 and 2000), Lawn (2006a, and 2013), Brennan (2008 and 2013), and Lawn and Clark (2010), among others, ISEW and GPI may not be perfect measurement tools for SD. Some criticisms of ISEW and GPI include the necessity for large volumes of data, many of which are often not available especially in less developed countries, differences in measurement elements across countries, possible arbitrary valuations on social and environmental effects. In spite of these shortcomings, Lawn (2003, 2006a, and 2013) show that the ISEW and GPI have firm theoretical backing, measure benefits and costs of the economic progress with some degree of accuracy, and serve as valuable means of assessing well-being. Thus Lawn argues that ISEW and GPI are still far superior SD indicators than GDP.

Lastly, whether ISEW and GPI are “weak sustainability” or “strong sustainability” indicators is still debatable. On the one hand, some argue that in principle, the theoretical foundation of ISEW and GPI is still based on Hicks’ definition of income (Brennan, 2008 and 2013). Economists who hold this view believe that instead of being contradictory to SNDP, ISEW and GPI modify SNDP with Fisher’s definition of income. Thus theoretically, SNDP, ISEW and GPI are all sharing the same theoretical concept: Hicks’ definition of income. Following this logic, since SNDP, ISEW and GPI are all intended to measure the maximum amount people can produce and consume without undermining their capacity to produce and consume the same amount in the future, ISEW and GPI may be “strong sustainability” indicators. On the other hand, it is argued that ISEW and GPI assume the diverse elements of comprehensive utility can be simply added together, which implies an increase in one element can be compensated by a decrease in another. Thus, in the empirical-calculative world, ISEW and GPI may be “weak sustainability” indicators (Dietz and Nuemayer, 2007, and Brennan, 2008). In sum, I conclude that SNDP, ISEW and GPI may be “weak sustainability” as well as “strong sustainability” indicators, depending on whether or not they can properly address the replacement cost of natural resource depletion, since the key distinction between “weak sustainability” and “strong sustainability” is the substitutability of natural capital with human-made capital.

Table 4.1: ISEW and GPI

Column	Item name	Description of indicator
A	Personal consumption expenditure	Household (private final consumption) expenditure on durable and non-durable goods and services.
B	An index of distributional inequality	An index of distributional inequality is introduced to account for the impact of income distribution on national welfare.
C (= A/B)	Weighted personal consumption expenditure	It is calculated by dividing the personal consumption expenditure (column A) by the index of inequality (column B).
D (–)	Cost of consumer durables	Amount paid in the current year on consumer durables such as cars, refrigerators and household furniture.
E (+)	Services yielded by existing consumer durables	Value of the services annually yield by previously purchased consumer durables.
F (+)	Services yielded by publicly provided human-made capital	Publicly provided human-made capital such as libraries, museums, roads and highways.
G (+)	Services provided by volunteer and non-paid household work	Value of volunteer and non-paid household work. Volunteer work is altruistic activities and intended to promote goodness or improve human quality of life, such as in response to a natural disaster. Non-paid household work include housekeeping gardening and parenting.
H (–)	Disservices generated by economic activity	Undesirable side-effects (irksome activities) in the economic process, including cost of noise pollution, cost of commuting, cost of crime, cost of underemployment (note 1), cost of unemployment (note 2), and cost of lost leisure time.
I (–)	*Defensive and rehabilitative expenditures*	*Human-capital produced to prevent the undesirable side-effect of the economic process including, cost of pollution abatement, cost of vehicle accidents, cost of family breakdown, and health expenditure.*
J (+)	*Net capital investment*	*Increase in the stock of producer goods above the amount required to keep the quantity of producer goods per worker intact.*
K (+)	*Net foreign lending/borrowing*	*It is included because economic sustainability of a nation is affected by the extent to which it relies on foreign funding to finance its current consumption.*
L (–)	*Cost of sacrificed natural capital services*	*Natural capital services lost (cost of the lost source, sink and life-support services provided by natural capital) in the economic process including, loss of farmland, loss of wetlands and old-growth forests, cost of resource depletion, cost of ozone depletion, cost of air, water and solid pollution, and cost of long-term environmental damage*

Sourced from Lawn (2003).

Note 1: cost of underemployment refer to value of idleness of part-time employees who want to work full-time. Underemployed worker are defined as those who work part-time but would like to work full-time. The cost of underemployment fall on the discouraged workers and their families, but the community and society also pays a price when limited work opportunities may lead to frustration, suicide, violence, crime, mental illness, or alcoholism and other substance abuse (Talberth, et al., 2006).

Note 2: cost of unemployment refers to value of idleness of the unemployed including, loss of output in the economy due to underutilisation of factors of production, loss of human capital due to declines in levels of skills, declining levels of health and increasing suicide among the unemployed, increasing levels of crime associated with higher unemployment, increasing rates of family breakdown, psychological impacts on the families of unemployed people, and trauma, stress and loss of self-esteem associated with being unemployed (Hamilton and Denniss, 2000).

Table 4.2: Comparison of ISEW and GPI items across studies

Column	Items in US GPI	Items in UK ISEW	Items in Australia GPI	Items in Austria ISEW
A	Year	X	X	X
B	Personal consumption	X	X	X
C	Income distribution index	X	X	X
D	Weighted personal consumption	X	X	
E	Value of housework and parenting	Services from domestic labour	Value of household and community work	X
		Expenditure on consumer durables		Expenditure on consumer durables
		Public spending on health and education	Public consumption expenditure (non-defensive)	Public consumption
		Private spending on health and education	Private spending on health and education	Defensive health cost
			Cost of unemployment	
			Cost of overwork	
			Services of public capital	
			Cost of problem gambling	
			Value of advertising	Cost of advertising
				Future consumption by net capital growth
F	Value of higher education			
G	Value of volunteer work			
H	Service of consumer durables	X		X
I	Service of highways			Service from roads
J	Costs of crime		X	
K	Loss of leisure time			
L	Costs of underemployment		X	
M	Cost of consumer durables	X		
N	Cost of commuting	X	X	X
O	Cost of pollution abatement			
P	Cost of auto accidents	X	X Cost of industrial accidents	X
Q	Cost of water pollution	X	Costs of irrigation water use Costs of urban water pollution	X
R	Cost of air pollution	X	X	X
S	Cost of noise pollution	X	X	X
T	Loss of wetlands	X		Loss of natural areas
U	Loss of farmland	X	Costs of land degradation	Costs of unsustainable soil cultivation
V	Loss of primary forests		X	
W	Cost of resource depletion	X	X	X
X	Carbon dioxide emissions damage		Costs of climate change	Costs of the greenhouse-effect
Y	Cost of ozone depletion	X	X	
Z	Net capital investment	X	X	
AA	Net foreign borrowing	X	X	Current account

X denotes the same name item as with US GPI. Items of US GPI are sourced from Talberth et al. (2006). Items of UK ISEW are sourced from Jackson and Marks (1994). Items of Australia GPI are sourced from Hamilton and Denniss (2000). Items of Austria ISEW are sourced from Stockhammer et al. (1997).

4.3.4 China's Green GDP

In the past 50 years, one prominent economic phenomenon is the growth of Chinese economy. After performing double-digit growth for three decades and lifting hundreds of millions Chinese from abject poverty, China is now the world's first largest economy, the largest exporter and the second largest importer (IMF, 2014). While Chinese economy rapidly grows, China's environment is also deteriorating dramatically. China faces severe environmental issues such as air pollution, water pollution, natural resource depletion, deforestation and desertification (see chapter 2 and 3). Increasing environmental pressure urges Chinese economy shifting from resource-intensive and pollution-intensive growth pattern to more sustainable and cleaner growth pattern.

Since the Hu Jintao and Wen Jiabao leadership came to power, Chinese government have been attempting to develop a more sustainable development model for Chinese economy. For instance, Chinese government's policies, such as "scientific development concept", "building a harmonious society" and "five-balancing goals", were introduced, and the idea of Green GDP were endorsed by all three policies above (Wen, 2004, Zhang and Chen, 2006, Rauch and Chi, 2010). In 2004, then China's Premier, Wen Jiabao announced that Green GDP would replace the conventional GDP as a new performance measure for local governments and party officials. This was widely recognised as a symbol that Chinese government began turning Chinese economy to be "Green", i.e. more environmental friendly. China's first Green GDP report was published two years afterwards and showed that financial loss caused by pollution was 511.8 million yuan (66.3 billion US dollar), which accounted 3.05% of China's total GDP (Sun, 2007). Since then, China's own Green GDP program has been implemented and various pilot studies have been carried out. However, just after five years, China's Green GDP project was officially cancelled for an indefinite length of time in March 2009. The reason behind this cancelation was mainly due to difficulties in data collection and complexities in valuation of natural resource depletion and environmental degradation (Rauch and Chi, 2010).

According to the China Green GDP Accounting Study Report (2004), China's Green GDP is calculated by deducting natural resource depletion costs and environmental degradation costs from the congenital GDP, which may be expressed mathematically in a formula as follows:

$$Green\ GDP = GDP - costs\ of\ natural\ resources\ consumption - costs\ of\ enviromental\ degradation \qquad (4.3)$$

China's Green GDP calculation has obvious limitations as follows. Firstly, although China's Green GDP formula is similar to the SNDP index, it misses out one part comparing with SNDP: the depreciation of human-made capital. This inconsistency leads to China's Green GDP formula overestimating China's true Green GDP, and theoretically causes China's Green GDP being inconsistent with Hicks' definition of income. Secondly, comparing to ISEW and GPI, China's Green GDP does not account for any income inequality, social benefits or costs, services from durables or non-market activities, indicating China's Green GDP is theoretically not consistent with Fisher's definition of income either. Last but not least, since China's Green GDP does not take into account any replacement cost of natural resource depletion, it is at the best an indicator of weak sustainability.

4.3.5 China's Comparable Green GDP (CGGDP)

Key challenges faced in China's Green GDP accounting are: firstly there is no consensus on environmental accounting elements, secondly values of pollutions and natural resources are difficult to determine, and lastly exact stocks of natural resources are difficult to estimate. Trying to tackle these difficulties, Liu and Guo (2005) propose a simplified approach for China's Green GDP, named as Comparable Green GDP (CGGDP from now on), which is calculated in a formula as follows:

$$CGGDP = GDP - Depletion\ of\ Natural\ Resources - Cost\ of\ Pollution \qquad (4.4)$$

The main aim of Liu and Guo (2005) is to develop a Green GDP calculation that is comparable between regions. To fulfil this aim, Liu and Guo (2005) facilitate their Green GDP calculation with the idea of "uniform formulation". The "uniform formulation" refers to two aspects: elements and prices. Regarding to elements, CGGDP includes exactly the same items of natural resources and pollutions for all provinces, to do so it assures same factors that have effects on SD are taken into account for all provinces. In terms of prices, CGGDP assumes static prices (constant over time) for natural resource depletion and pollution. These prices are either sourced from existing literature or estimated referring to market prices. Elements and prices of CGGDP are summarised in table 4.3.

Table 4.3: CGGDP elements and prices

Item	Price per unit (RMB)	Unit
Coal gas	1.79	m^3
Natural gas	2.31	m^3
Petroleum gas	2.88	Kg
Waste water treatment	0.63	Ton
Atmosphere treatment	0.000221	m^3
Solid waste treatment	76	Ton

Sourced from Liu and Guo (2005).

Moreover, though Liu and Guo (2005) use the same Green GDP formula as Chinese government, they put forward five assumptions to simplify the calculation as follows. (1) Production depreciation is not considered due to lack of relevant data. (2) The monetary values and costs are supposed to be invariable from 1998 to 2003, for the price index during that period was relatively constant. (3) Natural resource depletion simply includes the consumption of coal gas, natural gas and petroleum gas. Other resources are not included due to the lack of data. (4) Environmental loss simply includes the loss of pollution accidents and the cost of waste treatment for water, air and solid wastes. (5) The amount of water, air and solid wastes only include the parts produced by industries and residents in the city.

Although CGGDP does not account for social benefits and costs, depreciation of human-capital, income inequality, mainly due to data limitations, CGGDP does consider a set of selected natural resources and pollutions, which are major pollutions caused China's economic growth. Therefore CGGDP is a weak measure of green GDP and SD.

4.3.6 Natural resource depreciation calculation

It can be seen that Green GDP indices reviewed in section 4.3.5 consist of various items covering different aspects of an economy. Moreover, they also utilise various valuation methods. Particularly, valuation methods differ in the non-renewable resource depletion and long term environmental damage. In the case of non-renewable resource depletion, three most often employed valuation methods are: market value approach, replacement costs approach and the user costs approach (or El Serafy approach).

Comparable Green GDP follows the market value approach, in which market prices are utilised for valuing non-renewable resources. The reasoning behind market value approach is that non-renewable resources, as their name indicates, can only be exploited once, so their value should not be included in the sustainable income. The advantages of market value approach are that market prices are relatively easy to obtain. However, the shortcoming of market value approach is also obvious, since it may not reflect the full value of non-renewable resources, for instance the market prices of non-renewable resources do not account for any environmental or social value at all.

It may be worth noting that the market price of non-renewable resource is sum of extraction costs, scarcity rents and rents accruing to the party with market power if the market for non-renewable resources is not perfectly competitive. Extraction costs include all costs needed to bring the non-renewable resource to the market, such as compensations for labour and the service of man-made capital. Rents resulting from market power are transfer of income between economic agents. Since none of them is the real value of non-renewable resources, neither should form part of the calculation if the intent is to incorporate changes in the value of natural resource stocks into national income accounting. If the non-renewable resource market is perfectly competitive, the real value of resource should equal to the market price less the marginal extraction cost, which may be substituted by average cost in practice. Therefore the market value approach shares some common ground with the user costs approach, since both are based on the scarcity rent. Their difference lies in that, while the former uses the total amount of scarcity rent, and the later divides scarcity rent into a sustainable component and an unsustainable component – the user cost.

However, Liu and Guo (2005) do not consider extraction costs, or rents accruing to the party with market power, so Liu and Guo's (2005) Green GDP calculation implies strong assumptions that the non-renewable resource market is perfectly competitive and extraction costs are zero. We think these assumptions are strong and may influence our Green GDP value, so we consider extraction costs in our calculation, but assuming a zero value of rents accruing to the party with market power, implying the energy market is perfect competitive. We acknowledge that energy market in China may not be perfect competitive, we set up this assumption is mainly due to difficulties in finding data for rents accruing to the party with market power.

ISEW and GPI often follow the other two valuation methods for non-renewable resource depletion: replacement costs approach and user costs approach (or El Serafy approach). Replacement costs approach stems from the ISEW of the US (Cobb and Cobb, 1994), and follows the assumption that the non-renewable resource use cannot be prolonged forever, so it is not sustainable into the indefinite future. Therefore for any amount non-renewable resource depleted, there should be equivalently amount of renewable resource to replace. The replacement costs arise when replacing the non-renewable resource to renewable resource. By investigating the replacement costs of each barrel of oil equivalent in the period of 1950-1990, Cobb and Cobb (1994) propose a replacement cost of $75 with 3% escalation factor for non-renewable resource. Since then Cobb and Cobb's replacement costs approach has been employed by a number of Green GDP calculation, for example, Australia (Hamilton, 1999), Chile (Castaneda, 1999), France (Nourry, 2008), Netherlands (Bleys, 2007), Scotland (Moffatt and Wilson, 1994), Sweden (Jackson and Stymne, 1996), UK (Jackson, et al., 1997), US (Redefining Progress, 1999) and Wales (Matthews et al., 2003).

We should bear in mind that the replacement costs approach is based on a research published decades ago, which is invariably plagued by a high degree of uncertainty and arbitrariness. Therefore, the replacement cost of $75 with 3% escalation factor for non-renewable resource may not be appropriate in the contemporary era. For instance, one of the assumptions in Cobb and Cobb's (1994) study is that the all non-renewable resources consumed over a certain period must be replaced by equivalent renewable resources in the same period. However, this assumption has become increasingly less justifiable. In the case of energy resources, with the improvements in fracking technology, trillions of barrels of shale oil deposits have been added to existing commercially viable oil reserves. Moreover, crucial for arriving at the 3% annual cost escalator is the assumption that the unit cost of renewables will grow exponentially. But what have in fact happened in the past two decades in the energy sector is that, thanks to the technological innovations, the cost of renewable resources, especially that for solar and wind energy, has fallen dramatically. According to one estimate, "the average long-term cost of large-scale solar energy, for example, has dropped 20% just in the past year and nearly 80% in the last five years. Land-based wind energy costs have fallen by 15% in the last year, and by 60% in the past five years." (Guardian, 2004). Another consequence of the recent technological advances in the energy sector is that, to a growing extent, the argument against fossil fuel consumption stems from greenhouse gases emitted during the combustion process rather than from worries about the depletion of existing stocks. In the CGGDP index, the depletion of natural resources is approximated by the depletion of fossil fuels and the damages caused by greenhouse gas emissions are not included in the calculation of pollution costs. It may therefore be contended that the utility of the CGGDP index as an indicator of sustainable growth has decreased over time and is likely to continue declining in the future.

However, in the case of China, some renewable energy projects in China generate large capacities of energy and reduce renewables costs, but at the same time cause more environmental and social costs. For instance, the Three Gorges Dam flooded many archaeological and cultural sites, forced displacement of more than 1 million people, and caused a series of severe environmental consequences such as the increased risk of landslide, loss and fragmentation of wildlife (People Daily, 2009, and Xinhua News, 2009). Therefor if we consider these social and environmental costs of renewables, it is not certain to say costs of renewables are reducing over time. Thus we still assume an annual cost escalator for China.

Contrary to replacement costs approach, El Serafy (1989) argues that sustainable income can be separated from the non-sustainable income. Since non-renewable resources are irreversibly lost in the process of use, receipts from non-renewable resources extraction should not fully count as "sustainable income". Thus the rental income accrued from resource extraction is non-sustainable into the future and therefore should be deducted. This is known as the user costs approach or El Serafy approach. Green GDP studies employing El Serafy formula include Australian SNBI (Lawn and Sanders, 1999), and Chinese GPI (Wen et al., 2008).

Mathematically, the formula for computing user costs according to the El Serafy method[48] is given by:

$$UC = \frac{1}{(1+r)^{n+1}} \times [(P - AC) \times Q] \qquad (4.5)$$

where:

UC: user costs from non-renewable resource depletion

r: discount rate

n: number of periods to resource exhaustion

P: resource price

AC: average extraction cost

Q: extraction volume

Long term environmental damage, or costs of climate change refers to the cumulative damage associated with emissions arising from energy consumption such as greenhouse effect. Most Green GDP studies follow Daly et al. (1989) and Cobb and Cobb's (1994) proposal to levy a tax or rent on the amount of cumulatively consumed non-renewable energy[49]. This tax or rent is taken as $0.50 (in 1972 price) per barrel of oil equivalent of non-renewable energy. Despite that this tax or rent value ($0.50) is largely arbitrary, Daly et al. (1989) defence it on the ground that ignoring a major issue such as climate change because of the lack of generally accepted methodology would be wrong. Critiques for long-term environmental damage valuation mainly focus on whether its value should be accumulated over time or not. Although the greenhouse effect is due to the accumulation of greenhouse gas emissions, accumulating long-term environmental damage (climate change costs) leads to the multiple counting problem, since the total future damage of greenhouse gas emissions is already included in its marginal social cost. For example, in the ISEW of the UK (Jackson et al., 1997), carbon

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[48] Deviation of El Serafy can be found in the appendix of Neumayer (2000).

[49] Instead of energy consumption, some Green GDP studies choose to utilise the greenhouse gas emissions (Jackson et al., 1997). We opt for energy consumption due to our data availability.

emissions are accounted with marginal social cost for costs of air pollution, and are also accumulated to value the costs of climate change, which obviously leads to multiple counting of the total future damage (Neumayer, 2000). Despite of multiple counting problem, accumulating long-term environmental damage is employed vastly in existing literature, main publications are Belgian ISEW (Bleys, 2007), Chinese GPI (Wen et al., 2008), Swedish ISEW (Jackson and Stymne, 1996), and UK ISEW (Jackson et al., 1997).

4.3.7 Summary

In sum, this section reviews various Green GDP indices. It should be noted that these indices base on different theoretical foundations and therefore attempt to measure different aspects of SD. ISEW and GPI follow the Fisher's definition of income to measure welfare, so they take into account not only economic and environmental elements but also such social elements as income inequality and the value of non-market activities. In accordance with the concern for welfare measurements, these two indices are not obtained by making adjustments to the standard GDP but are instead based on consumption expenditure. By comparison, SNDP and CGGDP follow Hicks' definition of income, so they attempt to incorporate environmental sustainability into the calculation of GDP. And therefore SNDP and CGGDP are obtained by subtracting the costs of natural resource depletion and environmental degradation from GDP. In short, ISEW and GPI measure sustainable well-being, whereas SNDP and CGGDP are indicators for environmental sustainability.

It is worth noting that both SNDP and CGGDP account for costs of natural resource depletion and environmental degradation, but not physical capital depreciation. Thus these two Green GDP indices are making adjustments to the standard GDP rather than the Net Domestic Product (NDP), implying that physical capital does not depreciate or the depreciation rate of physical capital is zero. However it is estimated that depreciation rate of physical capital is likely to be not zero, main publications are Berlemann and Wesselhöft (2012), and Schundeln (2012). Moreover, as discussed by various growth models, depreciation of physical capital is an important factor to be considered for growth. For instance, in the Solow model, changes in depreciation of physical capital affect steady state capital and in turn steady state income per capita. Therefore, in our Green GDP calculations, we account for physical capital depreciation.

4.4 Methodology and Data

This section introduces methodology and data. We first calculate China's provincial Green GDP following Chinese government and Liu and Guo's (2005) formula. Then we carry out an empirical estimation to investigate the impact of trade openness on China's Green GDP following Talberth and Bohara's (2006) methodology. Thirdly, a description of our data set is also included in this section. Lastly, we discuss the selection of our estimator.

4.4.1 Chinese provincial Green GDP

We calculate China's provincial Green GDP by modifying the Green GDP formula proposed by Chinese government and Liu and Guo (2005) as follows:

$$Green\ GDP = GDP - Depreciation\ of\ physical\ capital - Depletion\ of\ Natural\ Resources - Cost\ of\ Pollution \qquad (4.6)$$

In general, our calculation of China's provincial Green GDP follows Liu and Guo's (2005) "uniform formulation" approach. We include exactly the same elements of natural resource and pollution for all provinces, as well as constant unit price for each element. To do so, we ensure the same factors influencing SD are taken into account for all provinces. Moreover, to improve Chinese government and Liu and Guo's (2005) calculation, we consider physical capital depreciation. In the existing literature, most studies on China's physical capital depreciation propose a fixed depreciation rate approach, main publications are Perkins (1998), Woo (1998), Hall and Jones (1999), Yang (2000), Wang (2000), Wang and Yao (2001), Gong and Xie (2004) and Zhang et al. (2007). Although physical capital depreciation rates may be different across provinces, we neglect this provincial variation due to lack of statistics. Therefore, we follow the fixed depreciation rate approach and assume 9.6% physical capital depreciation rate for all Chinese provinces; we choose 9.6% physical capital depreciation rate, because it is the average value in existing studies (Zhang et al., 2007).

However, due to data limitation, depletion of natural resources in our study includes only the provincial total energy consumption, which is the aggregate account of all sources of energy including non-renewable energy such as coal, oil, and gas, excluding renewable energy such as biomass energy and solar energy. In "costs of pollution", our study includes three pollutants: waste gas, waste water and solid waste, but these pollutants are contributing 80% of China's total air pollution, and 45.8% of China's total water pollution (Zhang, 2013).

In the case of value method, we also follow the methodology proposed by Liu and Guo (2005). Unit costs of waste gas, waste water and solid waste are directly sourced from Liu and Guo (2005), in which these unit costs are labelled as atmosphere treatment, waste water treatment and solid waste treatment. For depletion of natural resources, Liu and Guo (2005) propose to use market price. Thus we use the market price of coal to estimate depletion of natural resources, due that our provincial total energy consumption data are in the unit of standard coal. Standard coal is also known as the standard coal equivalent, which is the usual unit for measuring aggregate energy consumption in China. A metric ton of standard coal equivalent (tce) is equal to 29.31 GJ or 7 million kcal at low heat value. Since there is no price for standard coal, we utilise the market price of raw coal sourced from China Energy Databook 8.0., which reports the market price of raw coal of 140.19 yuan RMB for the year 2000. Because raw coal has an energy coefficient of standard coal of 0.7143[50] (1 unit of raw coal is equivalent to 0.7143 unit of standard coal), we estimate the market price of standard coal as $0.7143 \times 140.19 = 196.26$ yuan RMB/ton. All unit price and costs used in our valuation are reported in table 4.4.

Therefore our calculation of Chinese provincial Green GDP implies four deficiencies as follows. (1) The monetary values and costs are in constant 2000 price and supposed to be invariable from 1985 to 2010, for all our GDP data are also in constant 2000 price. (2) Natural resource depletion only includes the total energy consumption. Other resources are not included due to lack of data. (3) Cost of pollution simply includes the costs of waste treatment for water, air and solid wastes. (4) The amount of water, air and solid wastes only include the parts produced by industries due to data limitation.

[50] This figure is sourced from the National Bureau of Statistics of the People's Republic of China. http://www.stats.gov.cn/tjsj/tjbz/ [Accessed 29/03/2014].

Table 4.4: Green GDP elements and prices 1985-2010

Item	Price per unit (RMB)	Unit
Energy consumption	196.26	Ton
Waste water treatment	0.63	Ton
Atmosphere treatment	0.000221	m^3
Solid waste treatment	76	Ton

Sourced from Liu and Guo (2005) and our estimation.

Table 4.5: Green GDP items

Item name	Green GDP A	Green GDP B	Green GDP C	Green GDP D
Pollution	Abatement costs	Abatement costs	Abatement costs	Abatement costs
Non-renewable resources	Market prices	Market prices	Replacement costs	User costs
Long-term environmental damage	Not included	Included	Included	Included

It can be seen that in the calculation of China's provincial Green GDP, we employ the market value approach for the non-renewable resources but do not account for any long term environmental damage (labelled as "Green GDP A" in table 4.5) under the consideration of multiple counting problem (Neumayer, 2000). Alternatively we calculation three other versions of China's provincial Green GDP summarised as in table 4.5.

As review in section 4.3.6, we count the long term environmental damage from the cumulatively consumed non-renewable energy[51] following Daly et al. (1989) and Cobb and Cobb (1994). We take the \$0.50 (in 1972 price) per barrel of oil equivalent of non-renewable energy as a reference rent price and convert it into constant 2000 price yuan RMB as follows. First, we utilise the exchange rate between China and the US to convert \$0.50 (in 1972 price) into yuan RMB. Since the exchange rate is 1 US dollar = 2.2450 yuan RMB in 1972[52], rent price for China is 1.1225 yaun RMB in 1972 price. Second, we convert this rent price from 1972 price to 2000 price, but our Chinese national CPI data are only available from 1978, so we opt for the GDP deflator[53]. China's GDP deflator has an index value of 27.3674 for the year 1972 and 100 for year 2000, so the rent price at 2000 price is equal to:

$$p_{2000} = \frac{1.1225 \times 100}{27.3674} = 4.1017 \qquad (4.7)$$

[51] Instead of energy consumption, some Green GDP studies choose to utilise the greenhouse gas emissions (Jackson et al., 1997). We opt for energy consumption due to our data availability.
[52] Exchange rate data are sourced from Penn World Table (PWT) 7.1.
[53] China's GDP deflator data are sourced from World Bank's World Development Indicators (WDI) 2014. Comparing with China's national CPI data, the differences between GDP deflator and CPI are very small.

Lastly, since our energy consumption data are in the unit of (ton) standard coal and the rent price of 4.1017 yuan (2000 price) is for each barrel of oil equivalent, we utilise this rent price to estimate the rent price for each ton of standard coal. Because 1 toe (ton oil equivalent) = 7.4 barrel of oil[54], 1 ton oil = 4.1017 × 7.4 = 30.3528 yuan RMB. Since 1 unit of crude oil = 1.4286 standard coal[55], our estimation of rent price is: 1 ton standard coal = 30.3528/1.4286 = 21.2465 yuan RMB at 2000 price. We utilise this rent price for long term environmental damage in the computation of our Green GDP (Green GDP B, C and D in table 4.5).

In the computation of non-renewable resources depletion, we employ three approaches: market prices approach, replacement costs approach and user costs approach for Green GDP B, C and D respectively. In the market prices approach, we source the market price of coal from China Energy Databook 8.0., and estimate the price of standard coal as reported in table 4.4. The average extraction cost is 111.7515 yuan RMB sourced from Mao et al., (2008). Computation of Green GDP following replacement costs approach and user costs approach is discussed in the section below.

According to Cobb and Cobb (1994), to replace 1 barrel of oil equivalent of energy consumed with renewable energy resources costs $75 (1988 price) and is assumed to escalate by 3% per annum. We utilise $75 (1988 price) as a reference cost and compute our own replacement costs for China's Green GDP as follows. First, since the exchange rate between China and the US is 1 US dollar = 3.7221 yuan RMB in 1988, 1 toe (ton oil equivalent) = 7.4 barrel of oil and 1 unit of crude oil = 1.4286 standard coal, our estimation of the replacement cost for 1 ton standard coal is (75 × 7.4/1.4286) × 3.7221=388.4922 yuan RMB (1988 price). Second, we utilise China's national CPI[56] to covert this value into constant 2000 price, with the base year of 1978, CPI of 1988 is equal to 177.9 and CPI of 2000 is equal to 434, then our replacement cost at 2000 price is equal to 388.4922 × 434/177.9 = 947.7551 yuan RMB for the year 1988. Lastly, we also assumes an escalation factor of 3% per annum. Then the replacement cost for the year 1985 is $\frac{947.7551}{(1+0.03)^3} = 867.3302$ yuan RMB.

In the case of user costs approach, we make five assumptions as follows. (1) On the basis that market prices undervalue the absolute scarcity of non-renewable resources, the user cost is doubled. (2) Regeneration rate of the replacement assets is 1

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[54] Data sourced from International Energy Agency (IEA), http://www.iea.org/statistics/ [10/05/2014].
[55] Data sourced from China Energy Statistical Yearbook, 2014.
[56] Data sourced from National Bureau of Statistics of China http://www.stats.gov.cn/english/ [10/05/2014].

per cent per annum (i.e., r=1%). (3) Average non-renewable resource life is 50 years (i.e., n=50). (4) Market price is 196.2621 yuan RMB sourced from China Energy Yearbook 8.0. (5) Average production cost is 111.7515 yuan RMB sourced from Mao et al., (2008). These five assumptions are quite common in user costs approach, and the assumed values in these assumptions are believed be appropriate for China as suggested by Wen et al.'s (2008). Therefore the El Serafy (1989) formula for user costs estimation is as follows:

$$UC = 2 \times \frac{1}{(1.01)^{51}} \times [(P - AC) \times Q] \qquad (4.8)$$

where, P is market price (per ton), AC is average production cost (per ton) and Q is production volume (ton).

4.4.2 Trade Openness and Green GDP: Talberth and Bohara (2006) approach

Talberth and Bohara (2006) presume the level of Green GDP at any point in time can be explained by a variant of the standard Solow growth model, which suggests that Green GDP is a function of a province's capital stock, labour and influenced by other factors which may affect the productivity of these inputs such as economic openness (Solow, 1956 and 1957). In general notation, it may be expressed as follows:

$$GDPgrn_{it} = f(K_{it}, L_{it}, O_{it}) \qquad (4.9)$$

where $GDPgrn_{it}$ represents per capita Green GDP, K_{it} is capital stock, L_{it} is labour, O_{it} is a measure of international trade such as trade openness ratio, i and t represents province and year respectively.

Following Mankiw et al. (1992), equation 4.9 can be expressed in terms of a Cobb-Douglas type aggregate production function of the form:

$$GDPgrn_{it} = C_0 K_{it}^{\alpha} L_{it}^{\beta} O_{it}^{\gamma} e^{u_{it}} \qquad (4.10)$$

which can be specified in per capita term and represented in log-linear form as:

$$ggdp_{it} = c_0 + \alpha k_{it} + \beta l_{it} + \gamma o_{it} + u_{it} \qquad (4.11)$$

where all variables are in natural logarithm, $ggdp$ represents the per capita Green GDP, k is the capital stock per capita, l is the age dependency ratio, o represents trade openness ratio, α, β and γ are parameters, c_0 is a constant and u_{it} is the error term.

With respect to persistent concern, all variables should be stationary, since they are all bounded series (Russell et al., 2012). Our panel unit root test (see Persyn and Westerlund (2008) for a brief review) result provides some evidence that our variables are stationary (see report in appendix 4.1). Our results of panel unit root tests are consistent with the results of individual time series unit root tests, which are available from author upon request.

Moreover, due to dynamic concern, one period lag of the dependent variable (AR(1) term) is included. As discussed in Bond (2002), introducing this AR(1) term causes endogeneity problem, first difference transformation can eliminate the individual effects, but induce a non-negligible correlation between the transformed lagged dependent variable and the transformed error term. Therefore the Ordinary Least Square (OLS) estimator is inconsistent, and consistent estimates can be obtained using the instrumental variables (IV) estimator.

Thus basing on our unit root test result and Bond's (2002) discussion, we use first differenced series and the IV estimator in our estimation. As proposed by Talberth and Bohara (2006), there may be a nonlinear relationship between trade openness and Green GDP. Therefore we include the square term of trade openness to capture this nonlinearity. Our empirical specification is:

$$\vartriangle ggdp_{it} = b_0 + b_1 \vartriangle k_{it} + b_2 \vartriangle l_{it} + b_3 \vartriangle o_{it} + b_4 \vartriangle o_{it}^2 + b_5 \vartriangle ggdp_{it-1} + e_{it} \quad (4.12)$$

where, $\vartriangle$ means first difference, $ggdp_{it}$, k_{it}, l_{it}, and o_{it} are defined as aforementioned, b_1, b_2, b_3, b_4 and b_5 are parameters, b_0 is a constant and e_{it} is the error term.

4.4.3 Data Description

This section describes our data set. Most of our data are sourced from the National Bureau of Statistics of China and China Statistical Yearbooks for various years. The provincial energy consumption data are sourced from China Energy Statistical Yearbooks for various years. Capital stock data are sourced from Zhang (2007). We collect data for 29 provinces and municipal cities, excluding three special regions: Hong Kong, Macau and Taiwan and one autonomous region: Tibet, due to lack of data. To avoid possible inconsistency, Chongqing data are integrated with Sichuan data, together under the province name Sichuan. The time span of our data covers the period 1985-2010.

Some of our data are already described in chapter 3, such as waste gas, waste water, solid waste, GDP, capital stock, and trade openness. For saving space, we only discuss our energy consumption and age dependency ratio data here. These data are sourced from China Energy Statistical Yearbooks for various years.

Total Energy consumption

Provincial total energy consumption is the sum of various energy consumed in a province for a given time period in the unit of standard coal. It includes non-renewable energy such as coal, oil, and gas, but excludes renewable energy such as biomass energy and solar energy.

Age dependency ratio

We employ age dependency ratio as a measure of the labour. Age dependency ratio is defined as the ratio of people younger than 15 or older than 64 to the working age population (those ages 15-64). Data are shown as the proportion of dependents per 100 working-age population.

4.4.4 Selection of estimator

We discuss the selection of our estimator and report related test results in this section. We first utilise panel unit root test to examine possible presence of unit roots in our series. Secondly, we run our regression using OLS, fixed effect model and random effect model, and then utilise Hausman test to choose between fixed effect model and random effect model. Thirdly, for the endogeneity concern of our variables, we implement Durbin-Wu-Hausman (DWH) test. Due to dynamic concern, one period lag term of dependent variable (AR(1) term) is included. In the presence of endogenous variables and AR(1) term, OLS is inconsistent, and method of instrumental variables (IV) is suggested. In order to test the validity and relevance of our instruments, we carry out Sargan-Hansen test and underidentification test. An instrument is invalid if it is correlated with the error term. An instrument is irrelevant or weak if it is uncorrelated or only weakly correlated with the endogenous variable that is being instrumented. Fourthly, to test possible heteroscedasticity and autocorrelation problems, we implement Pagan-Hall (1983) test and Arellano-Bond (1991) test. Last but not least, to deal with all problems above, we utilise IV estimator with heteroskedasticity and autocorrelation (HAC) consistent standard errors.

4.4.4.1 Unit root tests

Many economic variables are time series variables, and thus they are believed to be random or stochastic process. A random or stochastic process is stationary if its mean, variance, autocovariance (at various lags) are time invariant. The stationarity of an economic variable has important implication in economics. If an economic variable is stationary, then it is mean-reverting and any shocks will have a transitory impact only. If an economic variable is non-stationary, then it is non-mean-reverting and any shocks will have permanent impact in the long run. Unless regressed nonstatoinary series are cointegrated, a regression of nonstationary series may be subject to the spurious regression problem providing misleading results (Granger and Newbold, 1974).

To examine the presence of unit roots in our data series, we utilise panel unit root tests. Panel unit root tests may be broadly categorised into three groups: early tests, first generation tests and second generation tests (see Persyn and Westerlund (2008) for a review of panel unit root tests). Among first generation panel unit root tests, Maddala and Wu (1999) test is often considered to be a superior test, since it uses data information more efficiently and has higher power. In the case of second generation unit root test, we choose to use the Pesaran (2007) test. Our panel unit root tests results are reported in appendix 4.1 (table 1). As shown in appendix 1, none of the variables in our estimations has a unit root, so all the variables are stationary.

4.4.4.2 Fixed Effect model versus Random Effect model

Since our panel estimations includes 29 provinces, and each province may have a specific effect. Both Fixed Effect (FE) model and Random Effect (RE) model address provincial specific effects, but the Fixed Effect (FE) model assumes the provincial specific effects are correlated with the explanatory variables, whereas Random Effect (RE) model assumes the provincial specific effects are uncorrelated with the explanatory variables. To statistically test which model is appropriate for our estimations, we utilise the Hausman test (Green, 2008, chapter 9). The null hypothesis of Hauman test is that the preferred model is Random Effect (RE) model. Our Hausman test result is reported in table 4.6. Since the p-value is less than 0.05, the null hypothesis can be rejected at 95% confidence level. Our Hausman test result prefers the Fixed Effect (FE) model, implying the time invariant provincial fixed effects are correlated with explanatory variables. Intuitively, we believe the Fixed Effect (FE) model is more appropriate in our study, for instance province specific effects such as geographic locations seem to be correlated with international trade, since as aforementioned in chapter 3 China's economic reform and open-up policy is geographically benefiting the coastal provinces.

Table 4.6: Hausman test result

Hausman	GDP	Green GDP A	Green GDP B	Green GDP C	Green GDP D
Chi2	82.0600	58.1200	63.3500	66.3000	76.4800
P-value	0.0000	0.0000	0.0000	0.0000	0.0000

4.4.4.3 Endogeneity of independent variables

As reviewed in the theoretical literature about trade and environment (section 3.2 in chapter 3), trade openness may not be exogenous in our estimations, since trade openness is believed to be influenced by countries' characteristics such as income and environmental degradation. Our dependent variable, Green GDP, is a function of income and environmental degradation, so there may be a loop of causality between

Green GDP and trade openness (similarly, GDP and trade openness). This loop of causality leads to endogenous explanatory variables problem, since the error term in our estimations cannot be considered independent of trade openness (Wooldridge, 2013). In the presence of endogenous explanatory variables, OLS estimator is biased and inconsistent, and instrumental variables (IV) estimator can be used. Thus it is necessary to test the endogeneity of trade openness. Following Baum et al. (2003), we utilise Durbin-Wu-Hausman (DWH) test for endogeneity. The null hypothesis of DWH test is that OLS is an appropriate estimation technique, only efficiency should be lost by turning to IV, therefore OLS is preferred. As shown in table 4.7, Durbin-Wu-Hausman (DWH) test result indicates that trade openness cannot be considered as exogenous variables, OLS estimator is not appropriate and therefore IV estimator is preferred[57].

Moreover, in existing empirical studies, current GDP is often believed to be influenced by previous GDP (Dollar and Kraay, 2004). This should be concerned too in the case of Green GDP. In order to address potential dynamic in GDP and Green GDP, an AR(1) term is included in our estimations. As illustrated by Bond (2002), this AR(1) term is correlated with the error term (in the first differenced model specification), and thus OLS estimator is biased and inconsistent. In this case, instrumental variables (IV) estimator can provide unbiased and consistent estimate of the coefficient of AR(1) term. Therefore, in the presence of endogenous variables (trade openness) and dynamic concern, we choose to utilise the IV estimator for our estimations.

Table 4.7: Durbin-Wu-Hausman (DWH) test result

DWH	GDP	Green GDP A	Green GDP B	Green GDP C	Green GDP D
Chi2	27.9770	24.9072	18.8752	9.7582	20.3265
P-value	0.0000	0.0000	0.0001	0.0076	0.0000

4.4.4.4 Validity of instruments

In IV estimator, the instruments must satisfy two requirements: it must be correlated with the included endogenous variable(s) (instrument relevance) and orthogonal to the error process (instrument exogeneity). Mathematically, these two requirements may be expressed as follows:

$$\text{Instrument relevance: } cov(z, x) \neq 0$$

$$\text{Instrument exogeneity: } cov(z, \varepsilon) = 0$$

[57] We also test the endogeneity of capital stock and labour using DWH test; and the result shows that capital stock and labour can be considered as exogenous variables. This result is available from the author upon request.

where z represents instrument(s), x represents endogenous variable(s) and ε represents the error term.

If an instrument is not relevant to the endogenous variable(s) or not orthogonal to the error term, then using this instrument in the IV estimation cannot remedy the endogenous variable(s) problem, instead it causes the estimator being biased and inconsistent. To test instrument relevance, we carry out the underidentification test. The null hypothesis of underidentification test is that the tested equation is underidentified, i.e. instrument(s) are not relevant to the endogenous variables. In the case of instrument exogeneity, we utilise the Sargan-Hansen test (Baum et al., 2003). The null hypothesis of Sargan-Hansen test is that the instrument(s) are satisfying the orthogonality conditions required for their employment. We use the lagged values of endogenous variables as instruments. Table 4.8 and 4.9 show that our instruments are relevant to the endogenous variables and orthogonal to the error, therefore they are valid instruments.

Table 4.8: Underidentification test results

	GDP	Green GDP A	Green GDP B	Green GDP C	Green GDP D
Chi2	19.1300	19.0800	9.2800	6.0200	9.5800
P-value	0.0003	0.0003	0.0097	0.0492	0.0083

Table 4.9: Sargan-Hansen (SH) test result

	GDP	Green GDP A	Green GDP B	Green GDP C	Green GDP D
Chi2	0.5590	0.3800	0.1690	0.1930	0.3320
P-value	0.7563	0.8260	0.6811	0.6606	0.5643

4.4.4.5 Heteroscedasticity

One of important assumptions in the Classical Linear Regression Model (CLRM) is that the disturbances in the regressions are homoscedastic. This is to say, the disturbances all have the same variance. When this assumption does not hold, we have the heteroscedasticity problem. Heteroscedasticity is common in panel data studies and has many causes as follows. Firstly heteroscedasticity may rise due to cross-sectional scale differences. Heteroscedasticity is generally expected if small, medium and large size of cross-sectional units are sampled together (Gujarati, 2004). In our data set of Chinese provinces, the sizes of Green GDP (GDP) vary between provinces, and the provinces with large Green GDP (GDP) values are likely to have larger variances of the disturbances, so heteroscedasticity is suspected. Secondly, heteroscedasticity may arise due to data collecting technique difference, since variances of disturbances are likely to be reducing as data collecting techniques improve. Our provincial data are aggregation of micro data from cities, towns or even lower levels, so there may exist cross provincial differences in collecting and calculating the data. Lastly, few outliers in our data set for some particular provinces and years may also cause heteroscedasticity problem.

We test the heteroscedasticity problem in our estimations using the Pagan-Hall test (Pagan and Hall, 1983). The null hypothesis is homoscedasticity. Our heteroscedasticity test results are reported in table 4.10. In all cases, we cannot reject the null hypothesis of homoscedasticity, implying that our estimations do not have heteroscedasticity problem.

Table 4.10: Pagan-Hall test result

Pagan-Hall	GDP	Green GDP A	Green GDP B	Green GDP C	Green GDP D
Chi2	6.5530	7.0980	2.1020	7.0240	1.7780
P-value	0.4768	0.4188	0.9101	0.3187	0.9389

4.4.4.6 Autocorrelation

Autocorrelation is a common problem in panel data. Autocorrelation problem arises when the disturbances between adjacent periods are highly correlated. In our data set, since pollution is mainly generated from dirty production process, and dirty production process is likely to be inertia, pollution normally cannot be reduced suddenly. Since Green GDP value is significantly influence by the pollution level, and GDP is also likely to be inertia, autocorrelation may exist in our estimations.

In our estimations, we only consider first order autocorrelation and how to alleviate it. We test the autocorrelation following Arellano and Bond (1991) approach. The null hypothesis is no autocorrelation. Our test result is reported in table 4.11. At 95% confidence level, our autocorrelation test results suggest we can reject the null only at the first order autocorrelation but not at higher orders, implying we have only first order autocorrelation problem.

In sum, we estimations face problems of fixed effects, endogeneity of trade openness, dynamic of dependent variables, and first order autocorrelation. Therefore, we propose to utilise the IV estimator[58] with heteroskedasticity and autocorrelation (HAC) consistent standard errors (Newey and West, 1994) for our estimation.

[58] We do not use the GMM estimator is because our panel is large T panel (time period T=26 and entity N=29). In the case of large T panel, GMM estimator faces too many instrument variables problem, and therefore it is not superior to the IV estimator (Roodman, 2009).

Table 4.11: Arellano and Bond (1991) test result

	GDP	Green GDP A	Green GDP B	Green GDP C	Green GDP D
AR(1)	0.0332	0.0422	0.0246	0.0187	0.0911
AR(2)	0.8017	0.6051	0.0565	0.1215	0.9146
AR(3)	0.8294	0.8316	0.0602	0.6814	0.9158
AR(4)	0.3529	0.3479	0.2752	0.8900	0.6648

p-value is reported in the table.

4.5 Results

In this section we present and discuss our results. Firstly, we present our calculation of China's Green GDP, and utilise our Green GDP data to test the TH and CTH. Secondly, we discuss our estimation results of equation 4.4. Lastly, basing on Talberth and Bohara's (2006) result from a group of developed countries, and our result from Chinese provinces, we put forward our hypothesis.

4.5.1 Green GDP

China's per capita GDP and Green GDPs are plotted against time in figures 4.1 and 4.2. Although adjusted for physical capital depletion, natural resource depletion and pollution costs, China's Green GDPs share a similar trend as its GDP. As aforementioned in chapter 3, China has gone through series of economic reforms and opened up its economy for foreign investment and trade since 1978. As a result, Chinese economy has performed sustainedly unprecedented double digit growth for more than three decades. Figure 4.1 and 4.2 show that not only per capita GDP but also per capita Green GDPs have grown exponentially over the period 1985-2010. Figure 4.3 shows that growth rates of China's per capita GDP and all Green GDPs have kept around 10% and been sharing a similar pattern from 1985 to 2010. This growth pattern is supported by the correlations between GDP and Green GDPs in table 4.12, which shows a strong positive relationship, since the correlations between GDP and Green GDPs are one or very close to one. Figure 4.1 to 4.3 and table 4.12 tell us that GDP and Green GDPs in China have a strong positive relationship, so they have a similar growth trend, implying that China's Green GDP growth is mainly driven by its GDP growth.

Figure 4.1 and 4.2 also show that China's national per capita Green GDP do not differ much by different computation methods, since the curves of Green GDP A, B and D are almost identical. This is also evident by table 4.13, which shows most Green GDPs and GDP have similar mean, standard deviation, minimum, and maximum values. The only exception is the Green GDP C. Figure 4.1 shows that Green GDP C gradually drifts away from other Green GDPs, and the gaps between Green GDP C and other Green GDPs are also widening over time. The key difference between Green GDP C and other Green GDPs is that Green GDP C includes an escalation factor. This difference is mainly resulted from our assumption that costs of renewables grow exponentially.

With respect to the gaps between GDP and Green GDPs, it can be seen that gaps between GDP and Green GDP A, B and D have gone up steadily, but gap between GDP and Green GDP C has increased sharply (figure 4.4). It is also worth noting that gaps between GDP and Green GDP A, B and D vary within a small range around 120 to 890 yuan, whereas gap between GDP and Green GDP C has a large range 707 to 5608 yuan (table 4.14). Since the key difference between Green GDP C and other Green GDPs is an escalation factor, we believe this increasing gap between GDP and Green GDP C is caused by the escalation factor, which is based on the assumption that finding renewable replacement for non-renewables is getting difficult and costs more over time. In contrast, if costs of non-renewables are constant over time as assumed by Green GDP A, B and D, gaps between GDP and Green GDP only rise slowly over the period 1985-2010.

Moreover, in the gaps between GDP and Green GDP, costs of non-renewables depletion consistently account for significant shares among all our four Green GDP indices. As shown in figure 4.5 and table 4.15, percentages of non-renewables depletion costs in Green GDPs have gone up gradually over the period 1985-2010. Green GDP C has higher percentages of non-renewables depletion costs than the rest Green GDPs, which is not surprising since Green GDP C assumes larger non-renewables depletion costs than the rest Green GDPs. In comparison, Green GDP D gives the lowest unit cost of non-renewables depletion, so it has the smallest percentage of non-renewables depletion costs almost all Green GDPs.

In terms of Green GDP to GDP ratio, Green GDP C shows the lowest rates among all Green GDPs (figure 4.6), because Green GDP C has bigger cost of non-renewable resource depletion than all other Green GDPs. Figure 4.6 shows that Green GDP to GDP ratios have gone up steadily over the period 1985-2010. Table 4.16 tells large proportion of Chinese GDP is actually Green GDP, and this is supported by all our four Green GDP indices. For instance, on average Green GDP account for more than 90% by Green GDP A, B and D, and account for over 75% by Green GDP C in the time span 1985-2010. Therefore by our Green GDP calculation, Green GDP increases as GDP increases and the rise of Green GDP is significantly contributed by GDP growth in China.

At regional level, we group Chinese provinces into three regions: East, Centre and West. In official and academic publications, the definitions of these three geographical regions are not consistent. In our study, East China includes 11 provinces and municipalities: Beijing, Fujian, Guangdong, Hainan, Hebei, Jiangsu, Liaoning, Shandong, Shanghai, Tianjin and Zhejiang; Centre China includes 8 provinces: Anhui, Heilongjiang, Henan, Hubei, Hunan, Jiangxi, Jilin and Shanxi; and West China includes 12 provinces and municipalities: Chongqing, Gansu, Guangxi, Guizhou, Inner Mongolia, Ningxia, Qinghai, Shaanxi, Sichuan, Tibet, Xinjiang and Yuanan. Figure 4.7 to 4.9 show that in these three regions, per capita Green GDPs and GDP share a similar trend. Green GDP C reveal a similar pattern as at the national level, since it is gradually drift away from GDP and other Green GDPs, and the gaps between Green GDP C and GDP and Green GDPs are widening over time.

Comparing between regions (figure 4.10 to 4.14), in terms of all four Green GDP indices, per capita Green GDP and GDP in the east grow much faster than Centre and West. Although all three regions have experienced significant growth in per capita Green GDP and GDP over the period 1985-2010, it is the east region that has performed much faster growth than the rest two regions. Beside, Centre region has slightly higher per capita Green GDP and GDP than the West regions. Furthermore, different computation methods of Green GDP make no change to above findings, indicating regional differences in China are consistent. This finding is also supported by statistics of per capital Green GDPs and GDP in three regions (table 4.17). It is easy to see that the east has the highest per capita GDP and Green GDP (by all four calculation methods) among the three regions over the period 1985-2010. For instance, the minimum GDP is 4068.1040 yuan and minimum Green GDPs ranges from 3294.8810 to 3939.5350 yuan in the east, whereas the minimum GDPs are 2462.5950 and 2007.7420 yuan in the centre and west respectively, and minimum Green GDP ranges are only 1674.8970-2337.6690 yuan in the centre and 1392.7120-1904.9920 in the west.

Provincial per capita Green GDP and GDP are plotted in figures 4.15 to 4.19. It is evident that per capita Green GDP at provincial level is also sharing the same growing trend with per capita GDP in all 29 provinces. And also provinces with relatively fast (slow) per capita GDP growth are accompanied by relatively fast (slow) per capita Green GDP growth. Moreover, east municipals such as Beijing, Tianjin and Shanghai, and provinces such as Guangdong, Jiangsu and Zhejiang, have experienced sharp increase in per capita GDP as well as Green GDP. Centre and West provinces have relatively lower per capita GDP and Green GDP than the east provinces. Moreover, our above findings are consistent with all Green GDPs, indicating that different accounting methods of Green GDP are all showing the same provincial differences among Chinese provinces.

In sum, our China's Green GDP data reveal noticeable points as follows. First, provinces that have relatively higher per capita GDP usually also have relatively higher per capita Green GDP. Second, provinces that have relatively higher per capita GDP growth are more likely to have higher per capita Green GDP growth too. Thirdly, it seems that per capita Green GDP and GDP are positively correlated and environmental loss such as natural resource depletion and pollution costs has not outweighed income to driven per capita Green GDP down in any Chinese province. Because per capita Green GDP and GDP are growing in all Chinese provinces, we cannot find any evidence for Threshold Hypothesis (TH). Existing literature tells us that there is a Green GDP threshold in China, after which further rise in China's GDP reduces its Green GDP. It is evident that China's Green GDP threshold is at the year 2002 (Lawn and Clarke, 2010). However though we find evidence that economic growth early-birds (East provinces) grow much faster than economic growth late-comers (Centre and West provinces) in Chinese provinces, there is no evidence that early-birds have reached the Green GDP threshold, so we fail to find any evidence for Threshold Hypothesis (TH) or Contracting Threshold Hypothesis (CTH) in China's national Green GDP or China's provincial Green GDP. Our results suggest even if there is a Green GDP threshold in China, this threshold may not be caused by non-renewable resource depletion or pollution costs, at least not the non-renewable resource and pollution considered in our Green GDP calculation. Last but not least, our above findings do not vary by different Green GDP accounting methods. Neumayer (2000) argues that evidence of TH found in Green GDP studies are largely due to the problematic accounting methods of Green GDP, such as escalation factor in replacement costs approach and multiple counting in long term environmental damage. However, our computation of Green GDP show that even with these problematic accounting methods, there is still no clear evidence supporting for either TH or CTH. Instead, Green GDP are always increasing with GDP in China, implying that as Chinese economy grows, China's welfare after addressing the negative environmental costs is also increasing, and China's economic growth is on a sustainable development path.

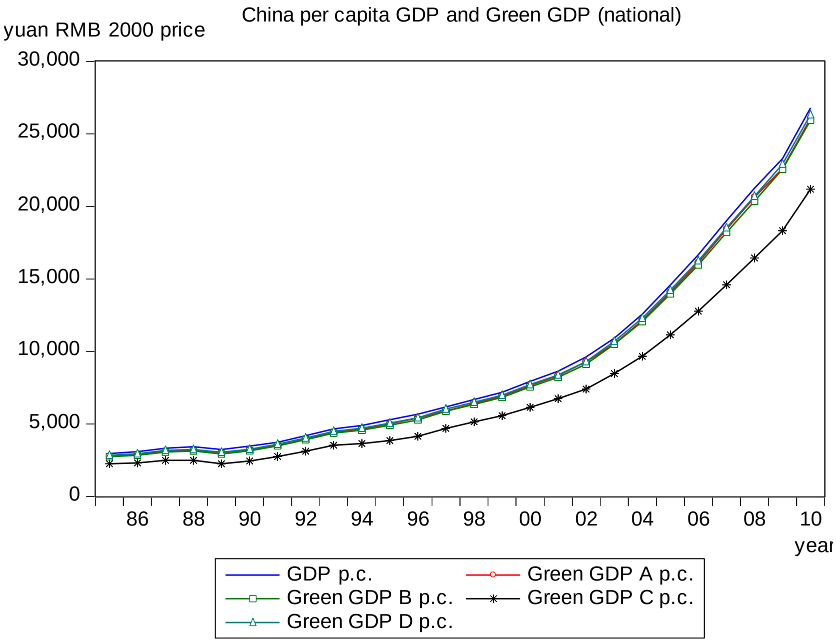

Figure 4.1: China per capita GDP and Green GDP (national)

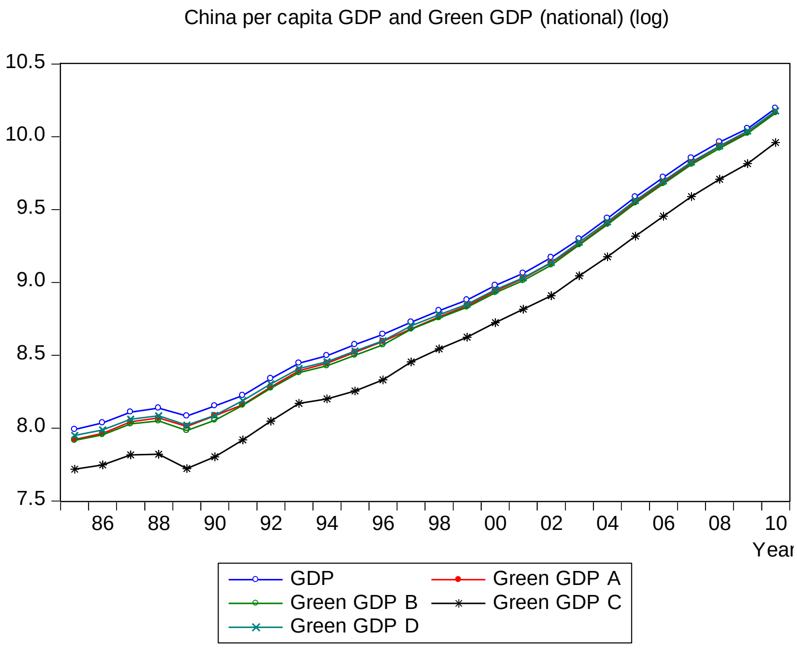

Figure 4.2: China per capita GDP and Green GDP (national) (log)

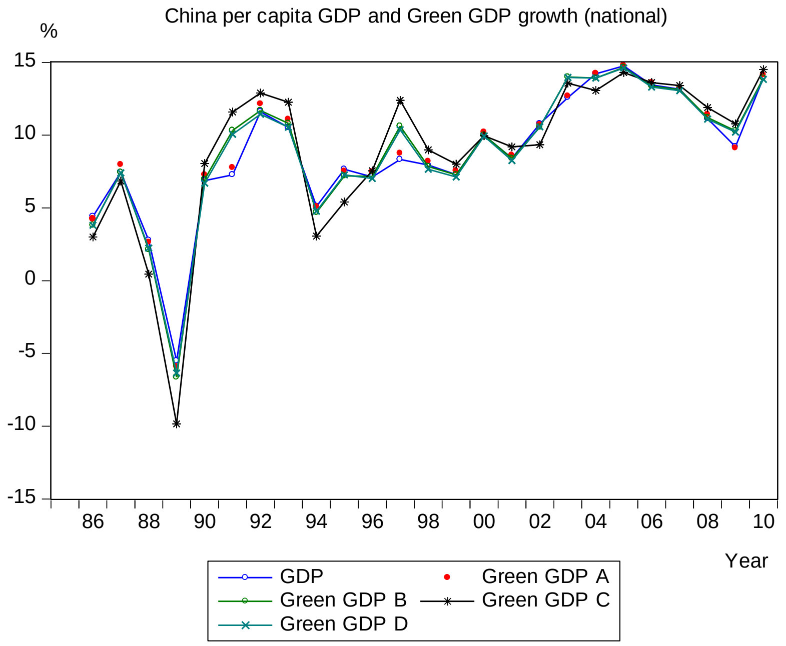

Figure 4.3: China per capita GDP and Green GDP growth (national)

Table 4.12 Correlations between GDP and Green GDPs (per capita)

	GDP	Green GDP A	Green GDP B	Green GDP C	Green GDP D
GDP	1.0000				
Green GDP A	0.9998	1.0000			
Green GDP B	0.9997	1.0000	1.0000		
Green GDP C	0.9894	0.9917	0.9923	1.0000	
Green GDP D	0.9999	1.0000	1.0000	0.9912	1.0000

Table 4.13 Statistics of GDP and Green GDPs (per capita)

	Mean	Std. Dev.	Min	Max
GDP	10051.7400	10332.3400	1483.8060	64838.1300
Green GDP A	9677.9310	10151.8200	1369.4990	63842.2900
Green GDP B	9575.2070	10108.3900	1360.7320	63951.9300
Green GDP C	7596.2230	8797.4590	688.5449	58054.7000
Green GDP D	9785.8400	10215.9800	1415.1660	64420.4000

Std. Dev.: standard deviation

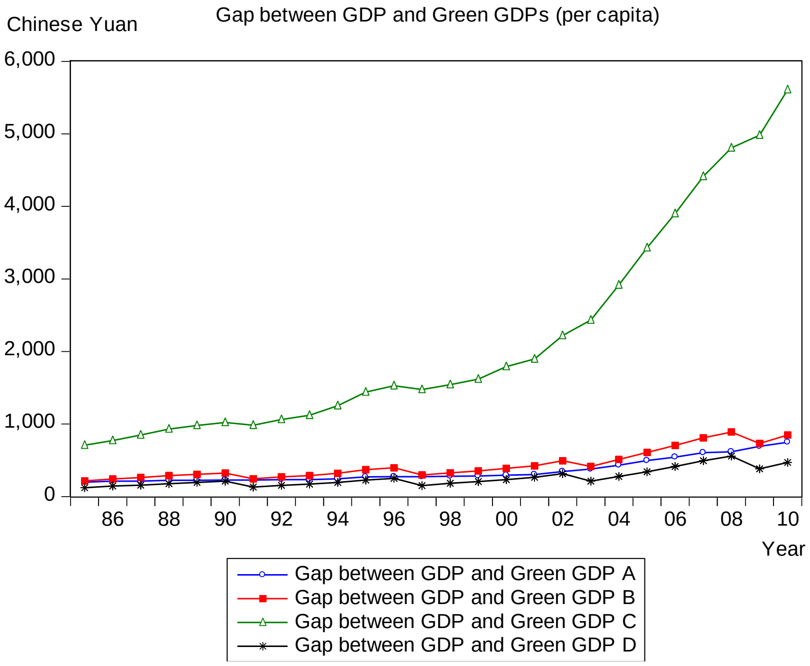

Figure 4.4 Gap between GDP and Green GDPs (per capita)

Table 4.14 Gap between GDP and Green GDPs (per capita)

	Mean	Std. Dev.	Min	Max
GAP A	349.0465	164.2912	198.8863	749.6452
GAP B	435.8085	202.7153	215.1298	890.0906
GAP C	2141.2940	1469.2450	707.4071	5608.0180
GAP D	255.4199	119.5228	120.7413	557.5183

Std. Dev.: standard deviation.

GAP A, B, C and D represents gaps between GDP and Green GDP A, B, C and D respectively.

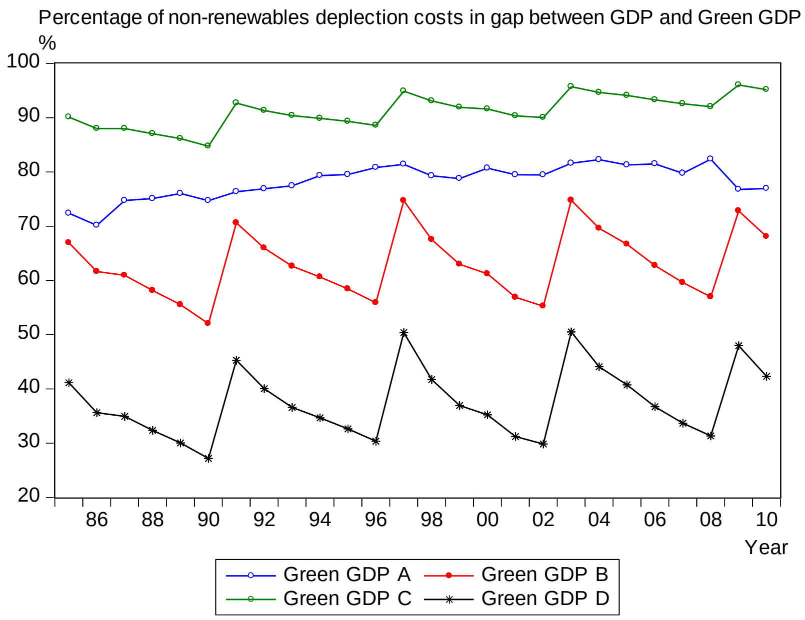

Figure 4.5 Percentage of non-renewables depletion costs in gap between GDP and Green

Table 4.15 Statistics of percentage of non-renewables depletion costs in gap between GDP and Green GDP

	Mean	Std. Dev.	Min	Max
Percentage in Green GDP A	78.2684	3.1302	70.1528	82.3457
Percentage in Green GDP B	63.0485	6.2857	52.0340	74.7732
Percentage in Green GDP C	91.2123	3.0229	84.7505	96.0101
Percentage in Green GDP D	37.4539	6.5076	27.1990	50.5149

Std. Dev.: standard deviation.

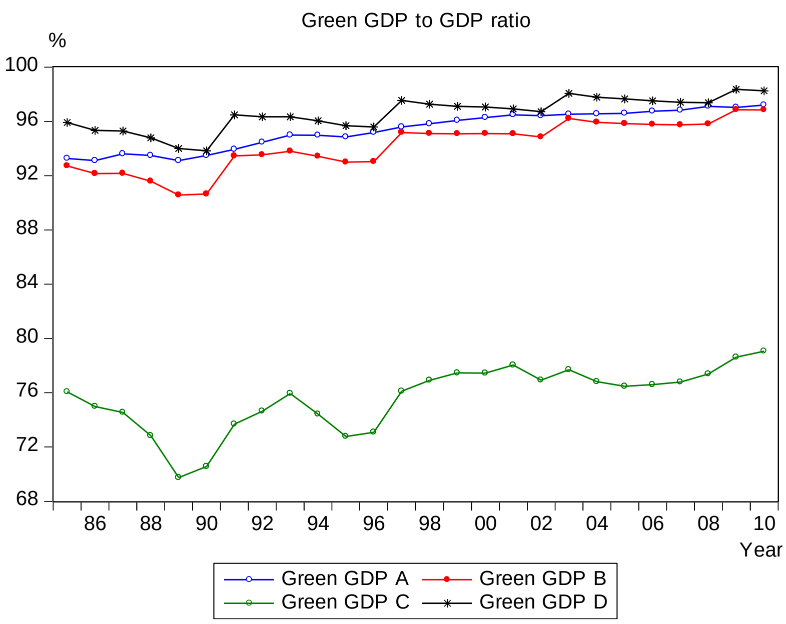

Figure 4.6 Green GDP to GDP ratio

Table 4.16 Green GDP to GDP ratio

	Mean	Std. Dev.	Min	Max
Green GDP A to GDP ratio	95.37151	1.407533	93.10855	97.20188
Green GDP B to GDP ratio	94.21018	1.82815	90.56299	96.86152
Green GDP C to GDP ratio	75.60158	2.361491	69.74145	79.06758
Green GDP D to GDP ratio	96.56385	1.237506	93.83484	98.35977

Std. Dev.: standard deviation.

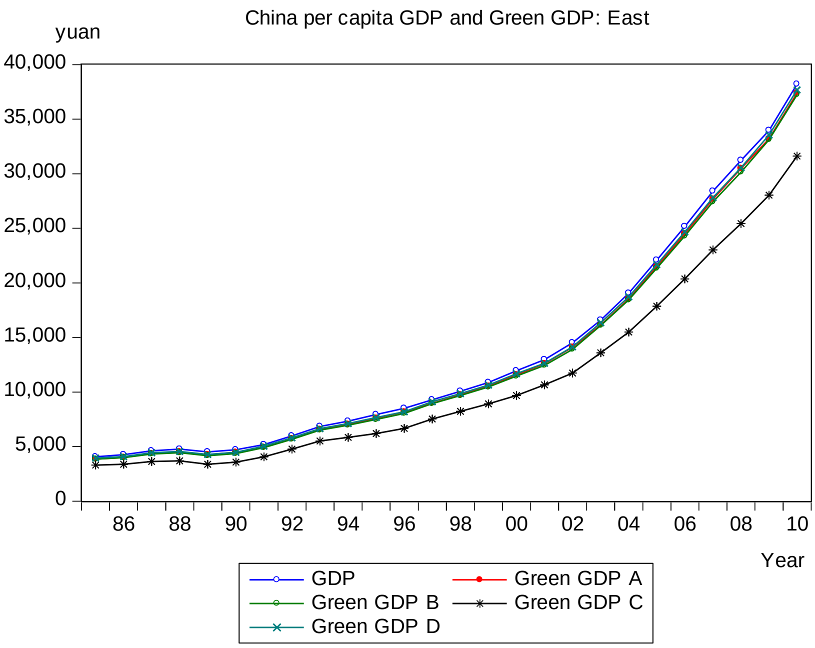

Figure 4.7: China per capita GDP and Green GDP: East

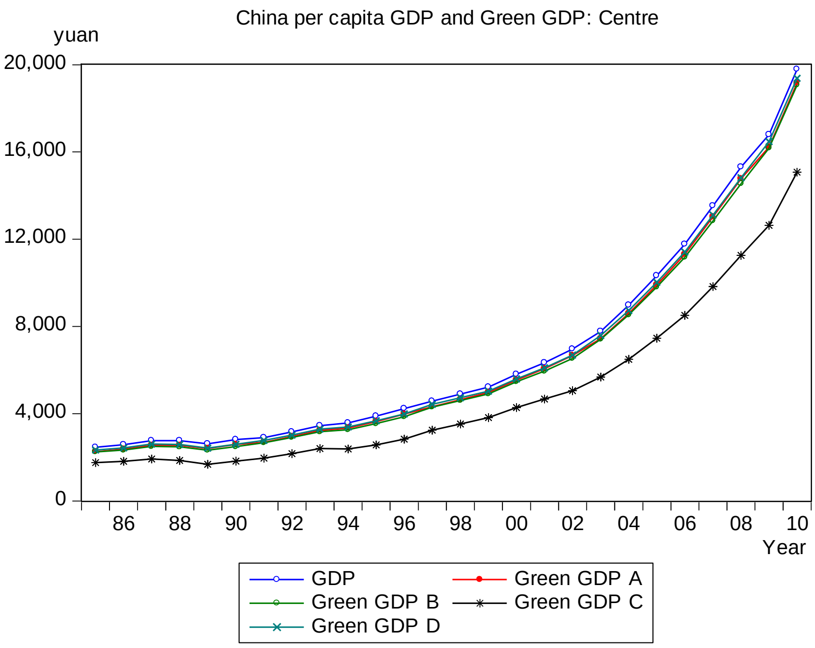

Figure 4.8: China per capita GDP and Green GDP: Centre

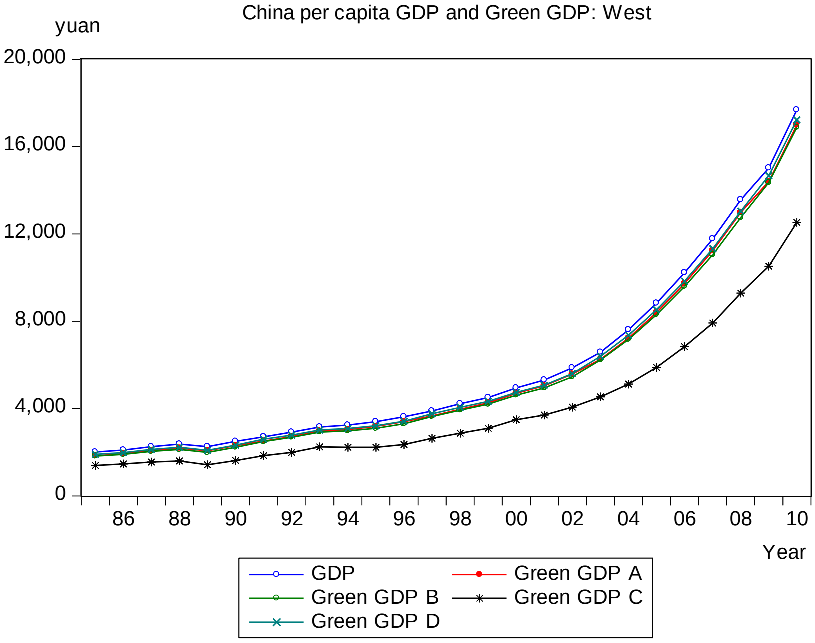

Figure 4.9: China per capita GDP and Green GDP: West

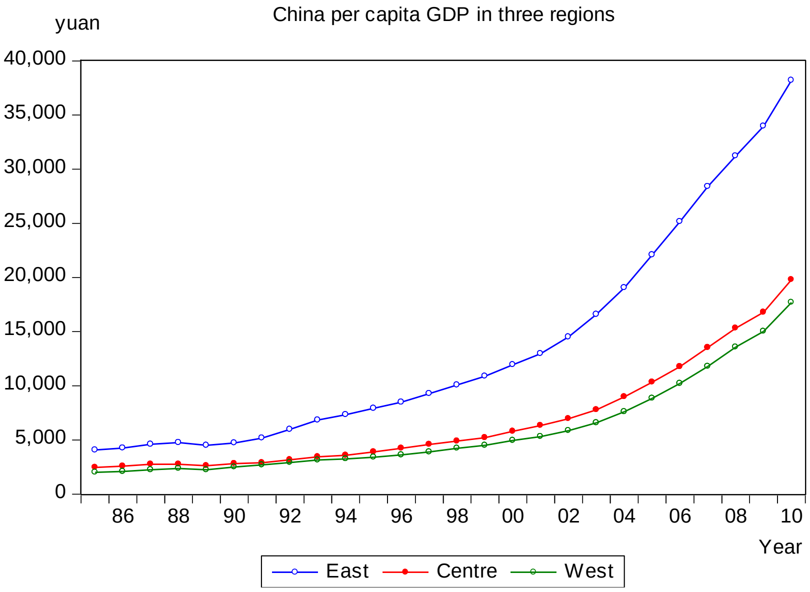

Figure 4.10: China per capita GDP in three regions

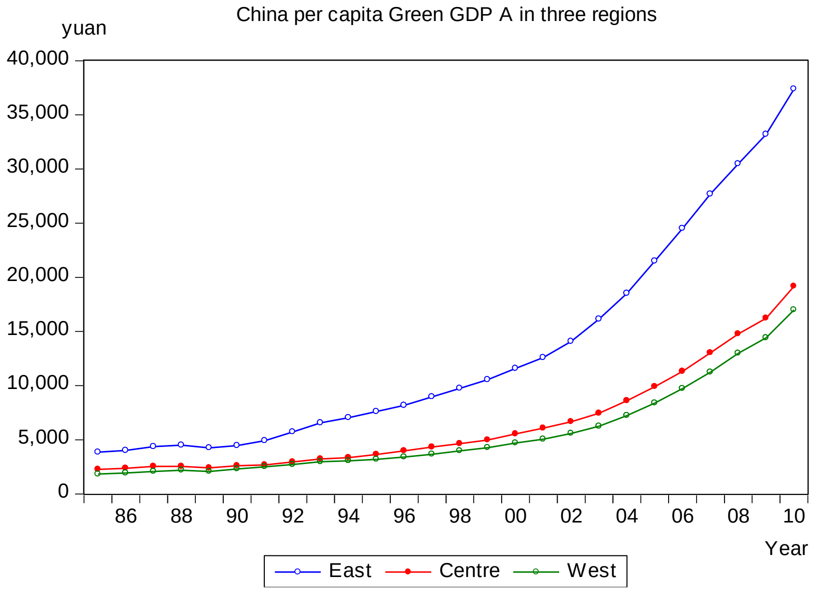

Figure 4.11: China per capita Green GDP A in three regions

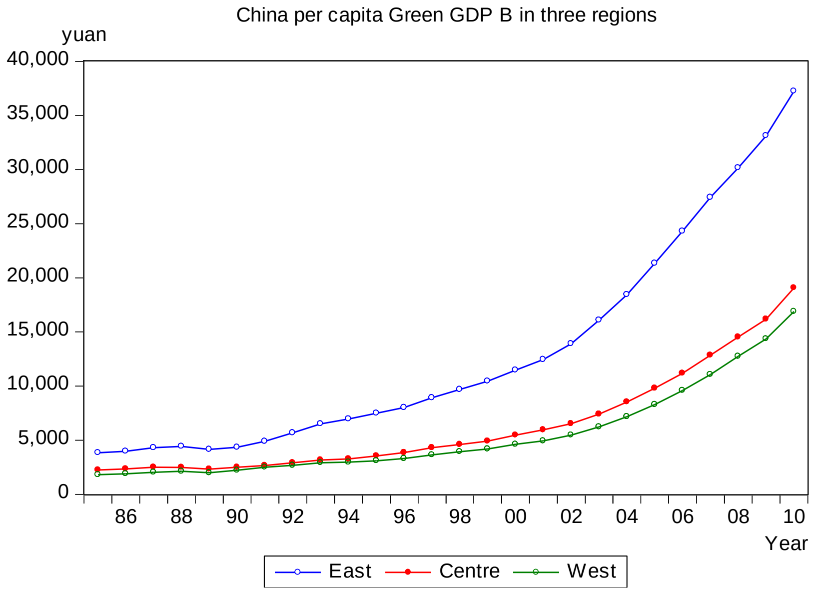

Figure 4.12: China per capita Green GDP B in three regions

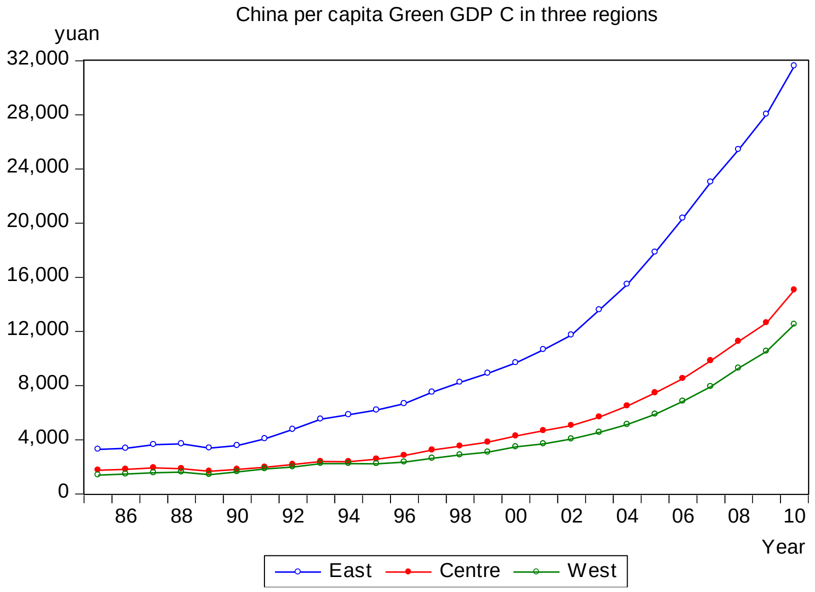

Figure 4.13: China per capita Green GDP C in three regions

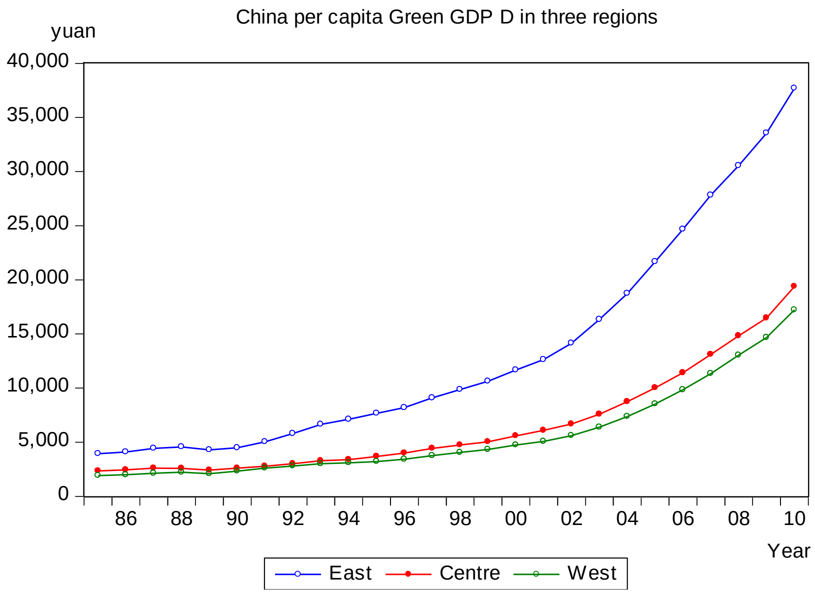

Figure 4.14: China per capita Green GDP D in three regions

Table 4.17 Statistics of GDP and Green GDPs (per capita)

East	Mean	Std. Dev.	Min	Max
GDP	13576.4700	10212.9600	4068.1040	38211.0200
Green GDP A	13168.6400	10024.0600	3852.9430	37379.2700
Green GDP B	13062.8000	9979.1380	3835.8170	37237.7700
Green GDP C	11005.7800	8437.7080	3294.8810	31619.0800
Green GDP D	13279.4600	10085.7000	3939.5350	37684.1100

Std. Dev.: standard deviation

East	Mean	Std. Dev.	Min	Max
GDP	6741.4920	4935.5480	2462.5950	19786.6900
Green GDP A	6429.8850	4809.4080	2259.7510	19166.0000
Green GDP B	6350.6730	4782.6620	2244.3400	19065.5200
Green GDP C	4873.8560	3756.4080	1674.8970	15069.8200
Green GDP D	6508.9610	4849.6600	2337.6690	19382.9300

Std. Dev.: standard deviation

East	Mean	Std. Dev.	Min	Max
GDP	5868.3300	4388.5930	2007.7420	17686.8900
Green GDP A	5564.9680	4233.6280	1836.1810	16993.0700
Green GDP B	5489.1940	4202.4950	1822.5710	16883.8300
Green GDP C	4016.8360	3059.9780	1392.7120	12527.7300
Green GDP D	5644.1230	4281.2940	1904.9920	17229.8700

Std. Dev.: standard deviation

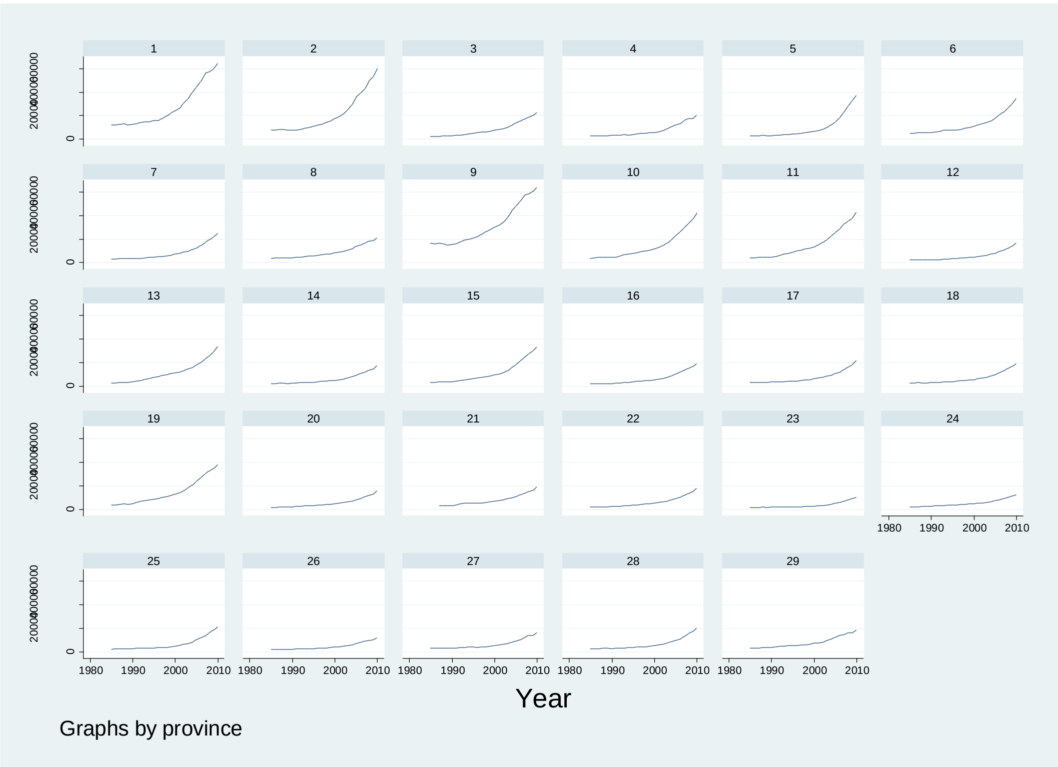

Figure 4.15: China per capita GDP by province

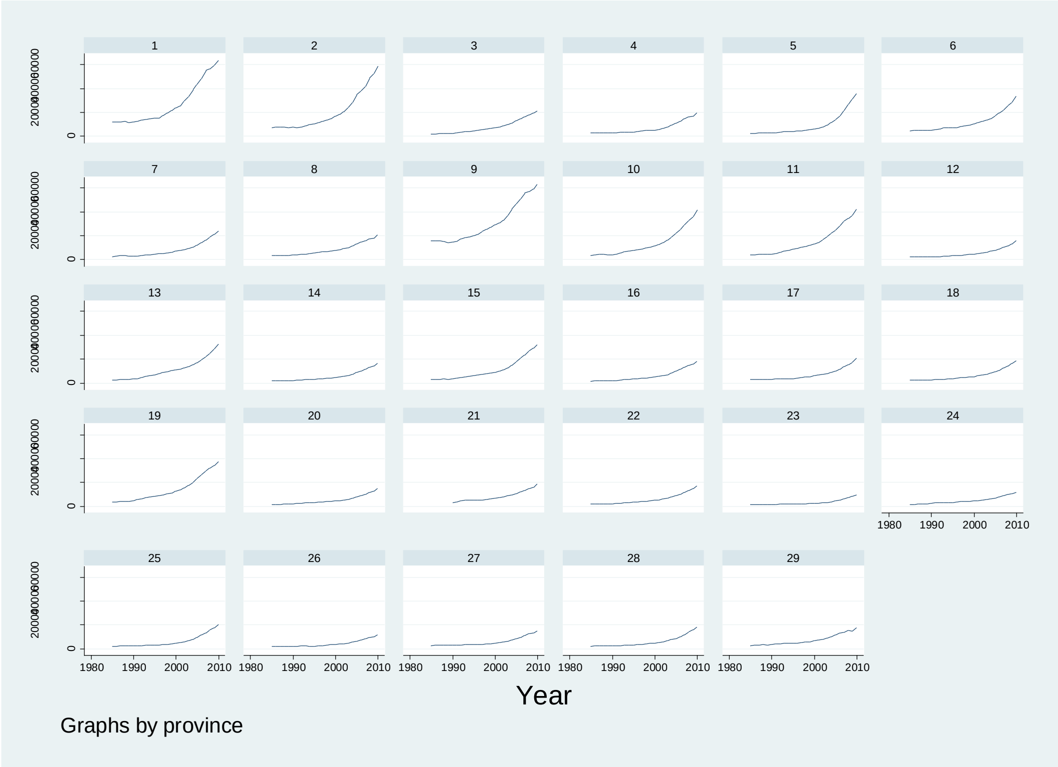

Figure 4.16: China per capita Green GDP A by province

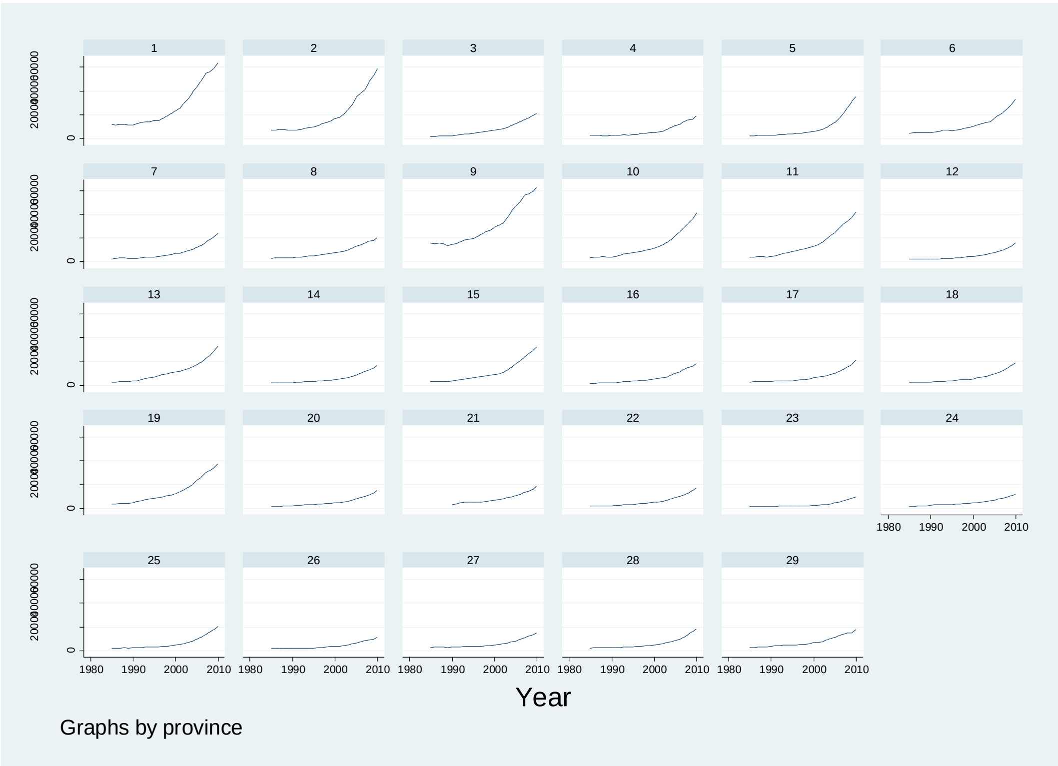

Figure 4.17: China per capita Green GDP B by province

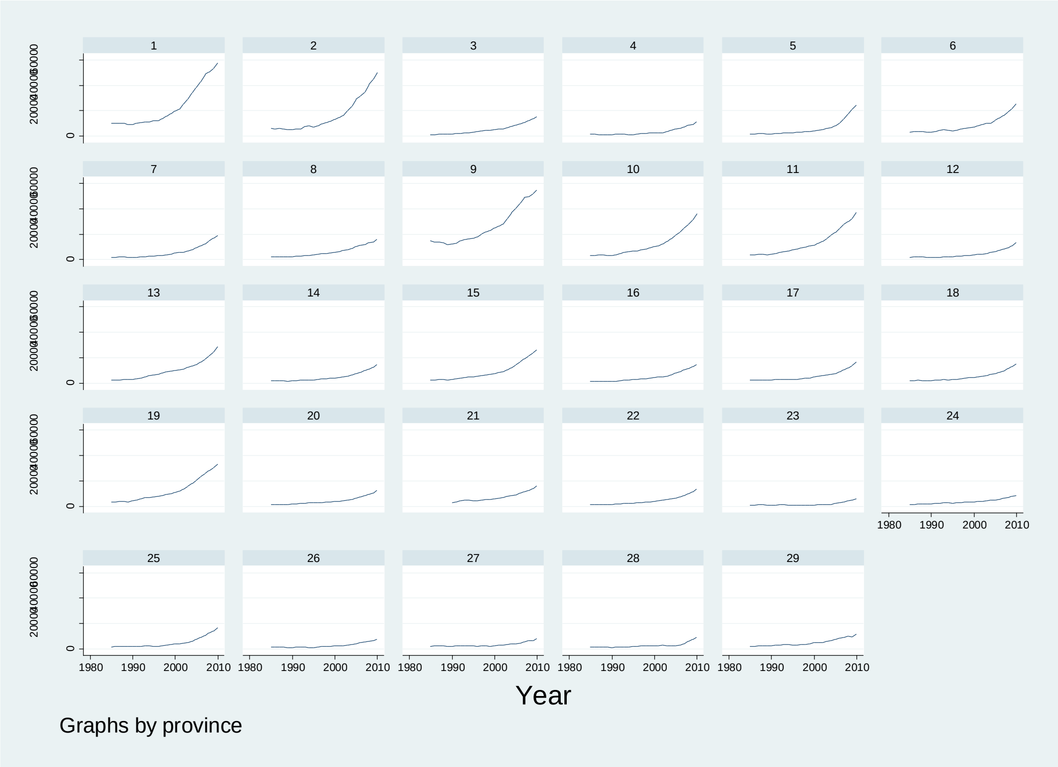

Figure 4.18: China per capita Green GDP C by province

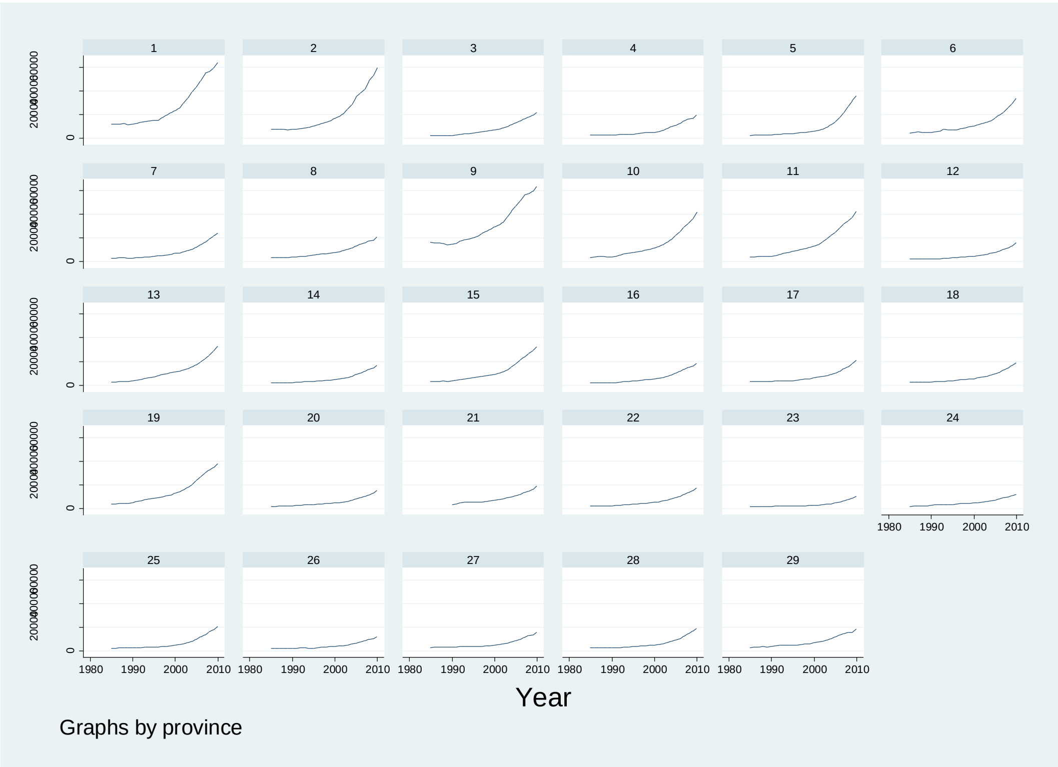

Figure 4.19: China per capita Green GDP D by province

Province code is as in figure 3.5

4.5.2 Estimation results

This section discusses our estimation result from the IV estimator. Since we find evidence of autocorrelation problem in our IV estimation, we utilise the Newey-West estimator to control for autocorrelation problem. Although our estimation result is consistent, the significance levels have been reduced. This is because the p-value for each coefficient is enlarged due to the HAC robust standard errors, which are greater than the usual standard errors (Wooldridge, 2009). Our results are reported in table 4.18.

As shown in table 4.18, the signs of capital and labour coefficients are as expected. As aforementioned in section 4.5, our estimation model is based on the Solow growth model, in which capital stock per capita is expected to have positive effect whereas age dependency ratio is expected to have negative effect on total output. Our estimation results show that coefficients of capital stock per capita and age dependency ratio have positive and negative sign respectively, implying capital and labour positively affect GDP as well as Green GDP. Therefore capital and labour are good for Green GDP and sustainable development in China. Moreover, this finding is consistent with all our Green GDP indices.

With respect to international trade variables, our estimation results consistently show that the coefficient of trade openness growth has statistically significant positive sign, but the coefficient of trade openness growth square has statistically significant negative sign. Our results indicate there is a positive nonlinear (inverted U) relationship between trade openness growth and Green GDP growth in China. This is to say, as trade openness increases, trade openness growth first increases the Green GDP growth until a threshold, after which further trade openness growth decreases the Green GDP growth. However, Talberth and Bohara (2006) find evidence of a negative nonlinear (U shape) relationship between trade openness growth and Green GDP growth in developed countries (table 4.19).

Therefore we conclude there is a threshold in the relationship between trade openness growth and Green GDP growth: before the threshold, trade openness growth decreases Green GDP growth in developed countries, but increases Green GDP growth in developing countries; however after the threshold, trade openness growth increases Green GDP growth in developed countries, but decreases Green GDP growth in developing countries. Hence, we propose our hypothesis as follows:

The relationship between trade openness and sustainable development are nonlinear and has different shapes in developed and developing countries. In developed countries, the relationship between trade openness and sustainable development has a

U shape; whereas in the developing countries, the relationship between trade openness and sustainable development has an inverted U shape.

Moreover, our finding may also reveal that the accounting elements matter for the empirical Green GDP studies. Talberth and Bohara (2006) utilise Green GDP computed following ISEW and GPI indices, which count environmental costs as well as social costs and benefits. But our China's provincial Green GDP only count environmental costs without any social costs and benefits due to lack of data. It seems that missing accounting elements, such as social costs and benefits, may have a huge impact on the empirical result of the trade-Green GDP relationship. However, since our China's provincial Green GDP in all versions provide qualitatively same result for the trade-Green GDP relationship, our estimation results may provide evidence that different accounting methods may not alter the empirical result at least for the case of China.

Table 4.18: Estimation results

	GDP	Green GDP A	Green GDP B	Green GDP C	Green GDP D
Δ Capital	0.0880	0.1022	0.1711*	0.2870**	0.1571*
Δ Labour	-0.1723***	-0.1718***	-0.2657***	-0.1597*	-0.2717***
Δ Open	0.2578***	0.2543***	0.2047**	0.1930*	0.2028**
Δ Open sq.	-1.9523**	-1.9350**	-1.2630*	-0.9943	-1.2648*
L. Δ Y	0.7225***	0.6817***	0.5141**	0.3548*	0.5432**

Δ is the first difference operator.
L. Δ Y: one period lag of the dependent variable.
Capita: capital stock per capita. Labour: age dependency ratio.
,,*** represents 10%, 5% and 1% significance level respectively.*

Table 4.19: Talberth and Bohara (2006) result

Green GDP	Talberth and Bohara (2006)
Δ Capital	0.93***
Δ Labour (note 1)	–280.63***
Δ Open	–0.57***
Δ Open square	0.01**
Constant	2.48***

,,*** represents 10%, 5% and 1% significance level respectively.*
Δ is the first difference operator.
Talberth and Bohara (2006) result is sourced from Talberth and Bohara (2006) table 4.
Note 1: Talberth and Bohara (2006) use age dependency ratio as a measure of labour. Talberth and Bohara (2006) finds age dependency ratio is I(2) series, so they take second difference for age dependency ratio in their estimation.

4.6 Conclusion

Sustainable development requires developing to meeting the present needs and at the same time protecting the environmental for meeting future needs. Sustainable development can be indicated by Green GDP. Previously, there is little study on China's Green GDP at provincial level. In this chapter, we calculate China's Green GDP for the period 1985-2010 and find clear evidence that China's provincial Green GDP are positively increasing with GDP.

Existing literature on the relationship between GDP and Green GDP proposes two hypotheses: Threshold Hypothesis and Contracting Threshold Hypothesis. Empirical studies at national level find that Green GDP grows as GDP goes up until a threshold, after which further rise in GDP decreases Green GDP, implying an inverted U shape relationship between GDP and Green GDP. This is known as the Threshold Hypothesis (Max-Neef, 1995). Moreover, Lawn and Clarke (2010) finds that a threshold exists in many countries' Green GDP, and also developed (developing) countries tend to reach the threshold early (later) at a higher (lower) level of Green GDP. This is known as the Contracting Threshold Hypothesis. However in the case of China's provincial Green GDP, there is no unambiguous evidence for either TH or CTH. In fact, we find that economic growth increases Green GDP in all Chinese provinces. This finding should come with surprise, as found in chapter 3, pollution and energy intensity (pollution and energy to GDP ratio) is reducing in all provinces over the period 1985-2010 (figure 10-12 in appendix 1 in chapter 3), implying China's economic growth is consuming less and less energy and producing less and less pollution for 1 unit of output. Therefore, despite of the large scale pollution, the technology improvement in China's economic growth is actually very significant. Thus in overall, China's Green GDP is in fact increasing.

For the relationship between trade openness growth and Green GDP growth, Talberth and Bohara (2006) find a U shape in developed countries, whereas we find an inverted shape relationship in one developing country: China. Basing on these two findings, we propose our hypothesis on the relationship between trade openness and sustainable development. We argue there is a nonlinear relationship between trade openness and sustainable development. Trade openness growth is good (bad) for the sustainable development in developing (developed) countries until a threshold, after which further trade openness growth is bad (good) for the sustainable development in developing (developed) countries.

Furthermore, our results may have indicated that accounting elements and methods have impacts on the empirical studies employing Green GDP. However, since our estimation shows qualitatively same result for Green GDP by different accounting methods, we conclude that our finding is at least consistent with different accounting methods for environmental costs in case of China.

It is worth noting that our Green GDP indices have a much narrower coverage comparing to ISEW and GPI, so it may not be comparable to Talberth and Bohara (2006). However, as discussed in section 4.3, our Green GDP indices share the same principle as ISEW and GPI, and since they are the only SD indices for Chinese provincial level to our knowledge, we should believe our Green GDP indices are better than GDP as SD measures for Chinese provinces at least for the time being. Therefore they may not be very appropriate, but currently the only Green GDP indices that can make comparison study against Talberth and Bohara (2006).

Moreover, our hypothesis are based on point estimates at Chines provincial level and a group of developed countries, but we are not emphasising on the threshold, because most SD measure such as our Green GDP indices, and ISEW/GPI in Talberth and Bohara (2006) are subjective and sometimes involve arbitrary assumption in the construction. Therefore, finding out the precise turning point may not be very interesting, since it is influenced seriously by the manipulation of index builder.

Also it may be questionable to draw inferences about a group of developing countries form experience of a single country, China. And our results might well have been driven by characteristics peculiar to China, which might get evened out when China was included in a group of developing countries. However, our defence may be that though China is a single country, but it is a big one, so provinces in China have the same size as many independent countries, therefore though our empirical study is limited to the experience of China, it is still valid to draw interesting and imaginative hypothesis from our study.

Last but not least, the reason why our study might have obtained an inverted U relationship between openness and green GDP when Talberth and Bohara (2006) find a U relationship based on OECD data, may be because there is a similar relationship between openness and GDP in both studies, but Talberth and Bohara (2006) have used data for countries that are beyond the threshold, whereas our study is based on evidence for countries before the threshold. Alternatively, since our result shows a similar marginal effect as Talberth and Bohara (2006), our study may indicate that trade has consistent marginal effect on Green GDP at developed and developing countries.

Limitations of our studies may also include. First, due to data availability, we do not count any social costs and benefits in our Green GDP accounting, which may lead to our computation of China's Green GDP being inaccurate measures of sustainable development. Second, Talberth and Bohara (2006) argue the gap between GDP and Green GDP should be employed in the trade-Green GDP relationship studies. We cannot carry out any empirical study following Talberth and Bohara's (2006) gap model due to lack of data. Thirdly, it is argued that revenue from depletion of non-renewable energy resources should be subtracted from provincial GDP in Green GDP accounting, since revenue from depletion of non-renewable energy resources is not sustainable income. However, we fail to access good energy production data and there are too many missing values for provincial energy production in China Energy Statistics Yearbooks for various years. It is due to this data limitation that we compute our Green GDP with energy consumption data only. Lastly, we only consider one indicator for non-renewable resources and three pollutants, which lead to our calculation of China's provincial Green GDP at best an overestimation of the real Green GDP, and therefore overestimating the sustainable development in China.

We acknowledge that our CGGDP as a Green GDP index also has obvious etlimitations. The depreciation of natural capital arises from three sources: extraction of non-renewable resources (e.g., fossil fuels, minerals), excessive exploitation of some renewable resources (e.g., fisheries, forests), and environmental degradation (e.g., pollution, loss of biodiversity, soil erosion). The CGGDP index, as explained in sections 4.3.5 and 4.5.1, is calculated as GDP less estimates of monetary values of fossil fuel consumption and pollution costs. Clearly, there exist circumstances under which the CGGDP index does not constitute an adequate approximation of the Green GDP index: e.g., among the different types of natural resource depletion, overuse of renewable resources preponderates over depletion of non-renewable resources.

We notice that Lawn and Clarke (2010) find evidence of a threshold for China, but our Green GDP data do not support their result. The Chinese national level Green GDP in Lawn and Clarke (2010) is calculated by Wen et al. (2009). After comparing with Wen et al. (2009), our study has similar calculation for environmental costs, but we do not account for any social costs, such as unaccounted house work. Therefore, we believe the evidence of a threshold for China at national level is caused by social costs but not environmental costs.

Appendix to chapter 4

Appendix 4.1: Unit root tests results

Table 1: Panel unit root test results

Maddala and Wu (1999)

Variable	t-statistics	p-value
GDP	124.8940*** [4]	0.0000
Capital	80.3050** [2]	0.0280
Labour	81.9450** [4]	0.0210
Trade openness	86.9600*** [1]	0.0080
FDI openness	99.3510*** [1]	0.0010
Green GDP A	128.6130*** [4]	0.0000
Green GDP B	85.2100** [2]	0.0120
Green GDP C	106.539*** [3]	0.0000
Green GDP D	85.1870** [2]	0.0120

Optimal lag numbers is selected according to Akaike information criterion (AIC) and reported in [ ]. Linear time trend is considered.

Pesaran (2007)

Variable	t-statistics	p-value
GDP	-3.0860*** [4]	0.0010
Capital	-1.3200* [2]	0.0930
Labour	-1.9280** [0]	0.0270
Trade openness	-1.9930** [0]	0.0230
FDI openness	-3.4240*** [1]	0.0000
Green GDP A	-2.0630** [4]	0.0200
Green GDP B	-3.1100*** [4]	0.0010
Green GDP C	-2.0340** [4]	0.0210
Green GDP D	-2.6790 *** [4]	0.0040

Optimal lag numbers is selected according to Akaike information criterion (AIC) and reported in [ ]. Linear time trend is considered.

Chapter 5: Conclusion

Since 1950s, many developing countries in the world have experienced significant economic growth as well as growth in international trade. Four emerging economies such as Brazil, China, India and South Africa are a key example of this. These four countries in the BRICs countries group, are emerging economic powers in the world because of their fast-growing economies, at the same time they are also in the BASIC countries group for environmental issues. Altogether, these four BASIC countries represent 40% of the world's population, contribute to 12% of world's total GDP, and contribute significantly to world's exports and imports, whilst at the same time generating roughly 32% of the world's CO_2 emissions and 37% of the world's SO_2 emissions (World, Bank, 2014, and Smith, 2011). These figures give the impression that (1) the rapid economic growth in BASIC countries has occurred at the cost of their natural environment, and (2) whilst stimulating economic growth, international trade may aggravate environmental degradation in BASIC countries.

Particularly, China is the world's most populous country with about 20% of the world's total population and is the largest economy, the largest exporter, and second largest importer, but also faces serious environmental issues (World Bank, 2014). For example, China is now the world's largest carbon dioxide emitter, contributing roughly to one third of world greenhouse gas. 85% of the country's surface and 60% of its underground water resources are polluted, and one-fifth of the farmland is contaminated by pollutants like cadmium and arsenic (Financial Times, 2014a, Reuters, 2014, and Verge, 2014). Meanwhile, Chinese people's health has been heavily affected by its polluted environment, for instance it is reported that poor air quality led to 1.2 million premature deaths in 2010. Due to severe adverse effects from pollution, the public has become more aware of China's environmental crisis, and begun voicing their concerns through both social media and public demonstrations. In March 2014, thousands of people converged on government buildings in the southern city of Maoming to protest the plan to build a new chemical plant (The Economists, 2014b). In May 2014, thousands of residents in Hangzhou demonstrated against a planned waste incineration plant (Financial Times, 2014b). Insomuch as the environmental issue is becoming a vital problem for China, Premier Li Keqiang has declared a “war on pollution” (Financial Times, 2014, Reuters, 2014, and Verge, 2014).

According to the latest IPCC report (2014), *the world needs a “Plan B” on climate change because politicians are failing to reduce carbon emissions*, pointing out that the economic growth in most countries cannot be sustained. Sustainable development (SD) is becoming a heated topic in media as well as academic studies, due to worldwide concerns over how long the earth’s finite resources can sustain the seemingly infinite human development. Moreover, there are also concerns about the increasing environmental degradation that may weaken the ability of the natural environment to meet the needs for future human development. In principle, sustainable development proposes a development path that can be sustained inter-generationally: it gives priority to the economic development for the present generation on the one hand, but on the other hand, it also emphases protecting the environment for future generations.

In a broad sense, the Environmental Kuznets Curve (EKC) hypothesis, Pollution Haven Hypothesis (PHH) and Green GDP can all be related to sustainable development, because if the income-pollution relationship in developing countries follows an inverted U shape EKC, then the “first pollute and then clean up” policy can be a choice for developing countries since their development may follow a sustainable development path; economic development and international trade will undermine sustainable development, if developing countries are pollution havens for developed countries; furthermore since sustainable development calls for better indicators than GDP for human well-being, the Green GDP, which adjusts conventional GDP with environmental costs, is one step further towards a measure of sustainable development.

This thesis tries to answer three important questions to sustainable development. First, are growth and trade bad for the environment in emerging economies? Second, are Chinese provinces becoming pollution havens for developed countries? Third, is trade bad for China's sustainable development? These three questions are important for sustainable development, because reasons as follows. Firstly from a global perspective, it could be argued that sustainable development is even more important for developing than for developed countries, since developing countries account for a larger share of the world's population. However, the majority of existing empirical studies are based on the experience of developed countries. Hence the research in this thesis begins to fill this gap in the literature by paying attention to the developing countries. Secondly, if growth and pollution in emerging economies are following an inverted U shape EKC, the "first pollute and then clean up" can be an applicable policy for developing countries, so it is important to investigate the relationship between growth and pollution in developing countries. Thirdly, if some provinces in China are becoming pollution havens rather than the whole country, Chinese government should use differentiate environmental policies between Chinese provinces. Last but not least, it is argued that trade may have positive as well as negative effects on China's Green GDP, since on the one hand trade stimulates growth rising income level and therefore living standard, on the other hand trade may cause pollution through direct effect such as rise in transportation increasing energy consumption (Cristea et al., 2013), and indirect effect such as rise in dirty good production generating pollution. So the overall effect of trade on Green GDP requires empirical study.

To address these issues above, we have carried out three independent studies as follows that have: (1) investigated the relationship between economic development, international trade and environmental degradation in BASIC countries, with a focus on testing the EKC hypothesis and analysing the role of international trade on environmental degradation. (2) Examined the impact of international trade on Chinese provincial pollution, including pollutants such as air, water and solid wastes. (3) Computed Chinese provincial Green GDP, assessing the international trade effects on sustainable development in China. In this last chapter, we provide a summary of our main findings, contributions, and policy implications, as well as our research limitations. Finally, a few possible extensions for future research are briefly discussed.

5.1 Summary of research findings and policy implications

Given the importance of BASIC countries for the world environmental issues, the relationship between economic development, international trade and environmental degradation in these countries is crucial for world sustainable development. The environmental impacts of BASIC countries' economic development and international trade were investigated in chapter 2, in which we tested the EKC hypothesis and studied the role of international trade on environmental degradation as suggested by the PHH and FEH. Our main findings can be summarised as follows. (1) Our empirical results show evidence that economic growth causes pollution, suggesting that environmental degradation is closely associated with economic growth as argued by the EKC hypothesis. (2) We also find evidence that there is inter-country heterogeneity in the shape and turning point of the EKC in the BASIC countries; and this inter-country heterogeneity also varies by different environmental degradation indicator. (3) Although many economists worry that international trade leads to BASIC countries becoming pollution havens, because of their lax environmental regulations, our estimation results provide no evidence that BASIC countries are becoming pollution havens for developed countries. Our finding should not come as a surprise, since the dirty industry (secondary industries and manufacturing industries) shares have been gradually decreasing over our sample period, implying that composition effects are not the main factor to BASIC countries' pollution. Therefore the composition effect induced by international trade should not be significant for BASIC countries' environmental degradation either. To our knowledge, there is no existing literature providing discussion for the reducing dirty industry shares in BASIC countries.

Chapter 2 reveals a growth-environment dilemma in the BASIC countries. On one hand, all four BASIC countries have large poverty population, and their economic development is the way to their poverty reduction. On the other hand, BASIC countries are also facing serious environmental issues, and their economic development significantly causes environmental degradation. Thus, the economic growth and poverty reduction in these countries may be at the cost of their natural environment. Moreover since there is no statistically significant evidence that international trade causes pollution in BASIC countries, in order to achieve sustainable development, BASIC countries should adjust their economic development towards more environmental friendly pattern. But at the same time, they do not need to alter their current international trade pattern, for the trade induced negative effect and positive effect cancel each other out, resulting in an overall insignificant effect on pollution in BASIC countries.

As currently the world the largest economy, China has experienced miracle economic growth and great involvement in international trade in the past thirty years. Meanwhile, it is also evident that China's environment has deteriorated dramatically in the same period. Although, at the national level, we fail to find any evidence that China acts as a pollution haven for developed countries, we cannot rule out that this aggregate result also holds across the different provinces given the significant inter-province disparities in economic development, international trade and environmental degradation. Because China is a big country, inter-province disparities in economic performance and in the strictness of implementation of environmental regulations, it is plausible to conjecture that the lack of support for the pollution haven hypothesis at the aggregate country level, may hide a situation in which poor Chinese provinces with relatively laxer environmental regulations are pollution havens, whereas rich Chinese provinces are not, due to their high income levels as well as strict environmental regulations. However, existing studies only cover relatively short time periods and provide ambiguous results about the relationship between trade and pollution. Utilising a long time period Chinese provincial air, water and solid wastes data, Chapter 3 provides evidence that trade openness and FDI inflows have benefiting effects for the environment (reducing pollution) in Chinese provinces. Our results provide no evidence that poor Chinese provinces are becoming pollution havens for developed countries. Moreover, we also question the assumption that high capital intensity industries are dirty industries, and provide empirical evidence that high capital intensity does not necessarily mean high pollution intensity, at least for the case of China.

Our results from Chapter 3 have a number of policy implications that may aid China's "war on pollution". Specifically, our results suggest that: (1) China does not need to restrict international trade and FDI inflows due to concern about their environmental impacts. (2) Instead, China should encourage international trade and FDI inflows in rich provinces as well as poor provinces due that international trade and FDI inflows do not have significant negative effects on the environment. (3) Given that we only see a negative trade induced technology effect on pollution in rich Chinese provinces, China should guide international trade and FDI inflows toward more technology but less pollution intensity sectors in poor provinces.

Sustainable development calls for a development path that balances economic growth and the natural environment, and suggests that GDP as the conventional measure of economic growth is no longer a proper measure for sustainable development. Green GDP, which includes the environmental costs of economic growth, is comparatively a better indicator for sustainable development. Attempts at computing Green GDP have been carried out in some countries, but little work has been done at the sub-national level (Clarke and Lawn, 2008). Of particular interest if that, due to China's worsening natural environment, the Chinese government wants to establish a Green GDP accounting. In 2004, then China's Premier, Wen Jiabao announced that Green GDP would replace the conventional GDP as a new performance measure for local governments and party officials. Since then, China's own Green GDP program has been implemented and various pilot studies have been carried out. However, due to data availability issues, just after five years from its inception, China's Green GDP project was officially cancelled for an indefinite length of time in March 2009 (China Economic Review, 2009). To shed light of the possible implications of using such a measure, Chapter 4 first computes China's provincial Green GDP following four different approaches. It then utilises Chinese provincial Green GDP for a discussion about threshold hypothesis and contracting threshold hypothesis. Lastly, we provide an empirical study on the relationship between trade openness and sustainable development.

Our main findings in Chapter 4 are as follows. (1) After computing Chinese provincial Green GDP, we find that Chinese provincial Green GDP increased over the period 1985-2010 in all three Chinese regions: East, Centre and West. However, the East Chinese provinces have much higher level of Green GDP than the Centre and West provinces, and the Green GDP gaps between the East, Centre and West have been growing, with Green GDP in the East increasing much faster than in the Centre and West. Our Chinese provincial Green GDP indicates that there are not only regional income disparities, but also significant regional disparities in sustainable development between rich and poor provinces. (2) Since we find no evidence that Green GDP reduced at national, regional or provincial level, we fail to find any support for either the Threshold Hypothesis (TH), or Contracting Threshold Hypothesis (CTH). Existing literature has shown that at the national level China's Green GDP (calculated following Genuine Progress Indicator (GPI)) peaked in 2002 (Lawn and Clarke, 2010). Our failure to find any threshold in Chinese provincial Green GDP implies that the threshold revealed by national GPI is not caused by the environmental costs. Since the Genuine Progress Indicator approach corrects the conventional GDP calculation with environmental costs and social costs, we argue that the threshold in China's national GPI revealed by Lawn and Clarke (2010) is due to social cost, implying social costs play the main role in dragging down China's national GPI. Therefore environmental costs and social costs are all important for China's sustainable development. (3) In the relationship between trade openness and sustainable development, the existing literature finds that trade openness growth has a negative nonlinear effect on Green GDP growth (Talberth and Bohara, 2006), implying a U shape relationship between trade openness growth and Green GDP growth. However, the existing literature is mainly based on Green GDP of developed countries. Utilising provincial Green GDP of a developing country, China, we find that trade openness growth has a positive nonlinear effect on Green GDP. Our finding indicates that China's trade openness growth increases Green GDP up to a threshold, after which further growth in trade openness reduces Green GDP. Since in our estimation the turning point of trade openness growth is well above the sample trade openness growth, we can conclude that trade openness is good for China's sustainable development, at least for the period 1985 to 2010. Thus, together with the results in Talberth and Bohara (2006), our findings enable us to put forward the following hypothesis:

The relationship between trade openness and sustainable development are nonlinear and has different shapes in developed and developing countries. In developed *countries, the relationship between trade openness and sustainable development has a U shape; whereas in the developing countries, the relationship between trade openness and sustainable development has an inverted U shape.*

Chapter 4 reveals the relationship between China's economic growth, trade openness and sustainable development as follows. (1) Despite causing severe environmental degradation, China's economic growth is still contributing to China's sustainable development. Therefore, it may not be necessary to sacrifice China's economic growth for achieving sustainable development in China. (2) However, the significant increase in Green GDP gap between rich and poor provinces suggests that the Chinese government should do more to balance the increasing regional disparities in China's sustainable development. (3) Last but not least, since international trade still positively contributes to China's sustainable development, there is no need to ease China's economic reform and open up policy for sustainable development.

5.2 Research limitations and future research

Although this thesis has extended and developed previous studies in several ways, it is still far away from a complete study on the relationship between economic growth, international trade and environmental degradation in developing countries. There are still numbers of specific limitations that may be worth noting as follows.

(1) In the study of BASIC countries in Chapter 2, we exclusively focused on two pollutants: CO_2 emissions and SO_2 emissions due to data availability, but as argued by Dasgupta, et al., 2002, de Bruyn and Heintz, 2002 among others, the relationship between economic growth, international trade and environmental degradation is likely to vary between different pollutants and environmental indicators. Therefore, it may be useful to employ our approach to study different pollutants and environmental indicators. (2) We should bear in mind that in the existing literature, the relationship between economic growth, international trade and environmental degradation is found

to vary across countries. However, we only focus on four BASIC countries, so our results may not hold for other countries. (3) We utilized the most common measure of international trade, trade openness, for our estimation. However, as revealed by other studies, there are many other indicators that may be even better measures than trade openness, so it may be useful to check the robustness of our findings to different trade indicators such as tariff rate.

(4) It may be argued that for the analysis carried out in Chapter 3, the simultaneous equation model (SEM) is an alternatively approach for studying the trade effect on pollution as proposed by Dean (2002) and He (2006 and 2007). We do not apply the SEM approach mainly due to our data limitation. (5) In our estimation, we assume that all parameters are homogenous, the validity of this assumption may be questioned. Heterogeneity panel estimators such as mean group estimator may be considered in future studies relax the homogeneity assumption in parameters.

(6) In the computation of Chinese provincial Green GDP, Chapter 4 only includes environmental costs, but as proposed by ISEW, GPI and other sustainable development indicators, social costs are also important for sustainable development. We do not include any social costs due to our data availability. Therefore, our calculation of China's Green GDP is likely to overestimate the true Green GDP in China. (7) We account for energy consumption and three pollutants in our Green GDP accounting, missing massive other non-renewable resources and various other pollutants. Again, this is due to our data limitation, so our Green GDP can be improved in the future, if more environment data become available. (8) Our threshold hypothesis is only based on our empirical studies, a theoretical study would help our understanding in future studies, for answering questions such as why there should be a threshold in the relationship between trade openness growth and Green GDP growth, why international trade may have

different effects on sustainable development in developed and developing countries, and what the optimal trade level should be.

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